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Fire Hazards and Mitigation Measures Associated with Seismic Damage of Water Heaters

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U.S. Department of Commerce
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U.S. Department of Commerce
William M. Daley, *Secretary*
Technology Administration
Gary R. Bachula, *Acting Under Secretary for Technology*
National Institute of Standards and Technology
Raymond G. Kammer, *Director*

PREFACE

The Congressional emergency appropriation resulting from the January 17, 1994 Northridge earthquake provided the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST) an opportunity to increase its activities in earthquake engineering under the National Earthquake Hazard Reduction Program (NEHRP). In addition to the post-Northridge earthquake reconnaissance, BFRL concentrated its efforts primarily in the study of post-earthquake fire and lifelines, and moment resisting steel frames.

BFRL sponsored a post-earthquake fire and lifelines workshop in Long Beach, California in January 1995 to assess technology development and research needs that will be used in developing recommendations to reduce the effects of post-earthquake fires. The workshop participants developed a list of priority project areas where further research, technology development, or information collection and dissemination would serve as a vital step in reducing the losses from post-earthquake fires. NIST funded a number of studies identified by the participants which are listed in NIST Special Publication 889.

BFRL, working with practicing engineers, carried out surveys and assessment of the damaged buildings and partially funded a SAC (Structural Engineers Association of California, Applied Technology Council, California Universities for Research in Earthquake engineering) workshop on seismic performance of steel frame buildings in September 1994. The objectives of the workshop were threefold: 1) to coordinate related interests; 2) focus on the problems observed in the performance of steel buildings; and 3) develop a research plan to solve the problems. NIST funded the research and engineering communities to carry out several of the proposed studies.

This report represents a part of these studies related to post-earthquake fire and lifelines sponsored by NIST as part of the Congressional emergency appropriation.

ABSTRACT

The basic objective of the experimental and analytical program detailed in this report is to perform an assessment of fire hazards and to develop mitigation measures associated with seismic damage of water heaters and related components in commercial and residential buildings. This research concentrates on restraint systems for ordinary water heaters (40 gallons to 150 gallons) using existing restraint methods proposed by the California Office of the State Architect and several manufacturers and improved restraints evolved in the course of this study. This report documents results, proposes modifications and introduces improved methods to those developed by the aforementioned organizations based on a four-week test session performed at the shaking table facility at the State University of New York at Buffalo and computer simulation.

The tests conducted utilized several earthquake records at a variety of peak ground acceleration levels on water heaters with various restraint systems. Test results are compared with computer simulation results. The response of the water heaters to the earthquake inputs was then analyzed to enable a quantitative evaluation of the restraint methods. Discussion and conclusions regarding the sensitivity of the water heaters and related components to earthquakes and the performance of the restraint systems are presented.

In addition to restraint measures, another means of fire hazard mitigation regarding water heaters during a seismic event is the installation of automatic gas shut-off valves. This option is another focus of this study. An assessment is made in this regard based on available test data performed on gas shut-off valves and on commercially available hardware designed for seismic applications.

ACKNOWLEDGEMENTS

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INTRODUCTION AND TEST OBJECTIVES

1.1 Introduction

Nonstructural components of buildings such as water heaters play an important role in modern society. The water heater offers the convenience of hot water to the owner at any time. This convenience can turn devastating in the event of an earthquake, which causes damage to equipment. The repercussions of a damaged water heater can be as low as the economic loss of replacement or as high as loss of life due to incipient fires caused by water heater damage, not to mention economic losses due to the fire caused by the damaged water heater.

After two recent earthquake events, Loma Prieta (1989) and Northridge (1994), surveys were taken to assess the damage to household water heaters. The University of California at Berkeley conducted a survey after the Loma Prieta event and the Southern California Gas Company surveyed their employees affected by the Northridge event. It is to be noted that the aforementioned surveys are in no way complete, but rather call to attention the need for fire hazard mitigation.

The UC Berkeley survey (Levenson, 1992) consisted of 850 random phone calls to residents of Santa Cruz, of which 299 responded. Approximately 199 of the 299 responders were able to complete the survey. From this survey, seen in Table 1, two observations can be made. The first observation is that 39% of the damaged water heaters had no restraint method applied. The other observation is that 37% of the damaged water heaters did have at least one strap used for restraint. This brings about the conclusion that restraints are necessary for water heaters but must be engineered to cause less damage to the heater itself.

The Southern California Gas Company's survey (Table 2) illustrates the same conclusion as reached in the UC Berkeley survey, that unsecured water heaters and strapped water heaters suffered relatively the same amount of damage (May and Garcia, 1994). One fact that is not illustrated in these surveys is the amount of fire damage caused by gas leaks attributed to water heaters. Approximately 20 structural fires were associated with water heater damage as reported by the Los Angeles County Fire Departments, illustrating the need to develop better mitigation measures to curtail damage caused by water heater gas leaks.

There are three options available to the commercial and/or residential owners of water heaters. The first option is to do nothing or null alternative. This alternative is not an option for residents of California (as per Bill AB 1890). As of July 1,1991, all new and replacement water heaters sold in California are to be braced, anchored, or strapped to resist falling or excessive horizontal displacement due to earthquake motion. Manufacturers of water heaters must add language to current instruction labels which

Table 1 UC Berkeley Survey (Levenson, 1992)

	Damaged		Undamaged		Total	
	#	%*	#	%*	#	%*
All Water Heaters	38	100%	261	100%	299	100%
Total Strapped	14	37%	87	33%	101	34%
Strapping Method:						
1 strap	4	11%	20	8%	24	8%
2 straps	7	18%	40	15%	47	16%
Other or Do Not Know	3	8%	27	10%	30	10%
In cupboard, but not known to have been strapped	9	24%	64	25%	73	24%
Now known to have been strapped or in cupboard	15	39%	110	42%	125	42%

Notes:

*Of the total water heaters in the given category (column).

No differences between damaged and undamaged water heaters are significant at the 95% confidence level.

Table 2 Southern California Gas Company Survey (May and Garcia, 1994)

	Damaged # (%)	Undamaged # (%)	Total
All water heaters	46 (40.4)	68 (59.6)	114
In enclosure:	18 (48.6)	19 (51.4)	37
Secured	6 (46.2)	7 (53.8)	13
Unsecured	12 (50.0)	12 (50.0)	24
Outside enclosure:	28 (36.4)	49 (63.6)	77
Secured	22 (40.7)	32 (59.3)	54
Unsecured	6 (26.1)	17 (73.9)	23

discloses the danger of falling due to excessive horizontal displacement under earthquake motion, and the California Office of the State Architect (OSA) must prepare generic installation instructions with standard details illustrating the strapping, bracing, and anchoring of water heaters. The public utilities, retailers, and manufacturers are not liable for the generic instructions provided to consumers as long as they have been approved by OSA, as complying with the requirements of the model codes in force on the date of approval (California Office of the State Architect, 1992).

The second option is to install a restraint system in order to protect the heater and subsequently protect against fire and property damage. The third option is the installation of an automatic gas shut-off valve.

The second and third feasible options are the main focus of this report with majority of the effort concentrating on restraint systems. Section 4 is devoted to the information gathered on the research conducted on automatic shut-off valves.

The choice of the appropriate restraint method plays a key role in insuring seismic safety of the water heater. There are, however, other factors that must be addressed. Since the law requires all homes and businesses in California to restrain their water heaters, a restraint method must be durable, cost effective, and easy to install. The term "cost effective" means that the total price of the restraint method must be reasonable so as not to deter the average homeowner. The ease of installation can be described as the ability of the average consumer to purchase the necessary materials (i.e., from a hardware store) and set up the restraint system correctly in a reasonable amount of time. The durability question will be analyzed in this report, but other constraints must be kept in mind upon final evaluation of the restraint methods.

The earthquake tests described in this report consist of a four-week test session conducted between September 10, 1996 and October 11. 1996. The major test objective was to evaluate the different methods of restraint for water heaters, and to assess their suitability for use in a seismically vulnerable area. Another objective was to research the feasibility of installing automatic gas shut-off valves. This report provides comprehensive test results obtained during the testing session as well as results through computer simulation, and an overall assessment of their significance. Regarding gas shut-off valves, a technical and economic assessment is made based on available hardware developed for this purpose and on available test data.

SECTION 2

TEST EQUIPMENT AND RESTRAINT METHODS

2.1 Test Set-up

2.1.1 The Earthquake Simulator

The testing series were carried out on the shaking table at the State University of New York at Buffalo, which provided the base motion to the equipment being tested. The shaking table has dimensions of 12ft. X 12ft. (3.66m X 3.66m) with a capacity of 110 kips (50 mtons) and an advanced control system. It has three degrees of freedom (DOF) actively controlled; they are horizontal, vertical and roll.

The system has two horizontal actuators with a capacity of 70 kips (32 mtons), which can provide a horizontal acceleration of 0.625g with maximum load. Four vertical actuators with a total capacity of 220 kips (100 mtons) can accelerate the system with 1.05g at maximum load. With lighter loads, the system can produce larger accelerations (up to 4.0g horizontally and 8.0g vertically). A schematic sketch of the system is shown in Figure 1.

2.1.2 Frame Structure

The tests were performed using commercially available water heaters fastened to a three-sided stud wall frame. The dimensions of the frame are 4ft. X 4ft. X 8ft. and are 8ft. high. The walls were fastened down to the shaking table using 1in. diameter bolts and 1/2in. CDX plywood was screwed into the top headers of the frame walls. The same plywood was also used as sheathing for the interior wall faces where the restraint systems were placed. This construction was used to simulate the ordinary basement or garage where water heaters are typically stored. Provisions for anchoring into concrete are given in all OSA installation instructions. Schematics and photographs of the three-walled frame are given in Figures 2 and 3.

2.1.3 Instrumentation

Horizontal acceleration measurements using accelerometers were made at several locations on the shaking table, frame structure, and water heaters being tested. The placements and designations for the accelerometers are shown in Figure 4. For all measurements the sampling rate was set at 100 samples/ second.

The horizontal displacements of the water heaters were measured using Temposonic displacement transducers. Displacements were measured at three heights on the water heaters: at gas line intake point, midpoint of heater, and at the top of the heater. For some of the tests two water heaters were tested simultaneously and for other tests only one was used. The locations of the displacement transducers are illustrated in Figure 4.

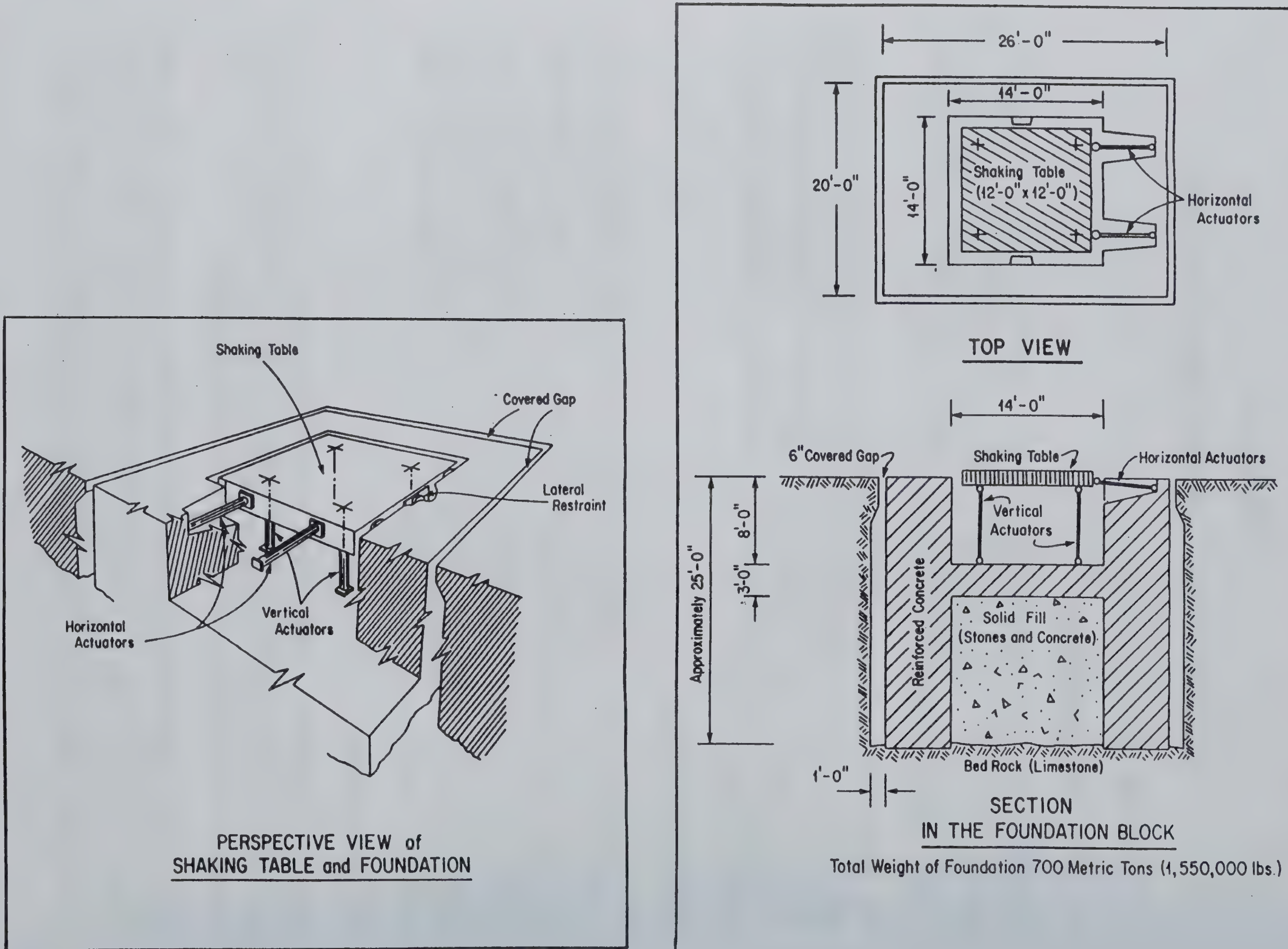


Figure 1 Schematic Sketch of the Shaking Table

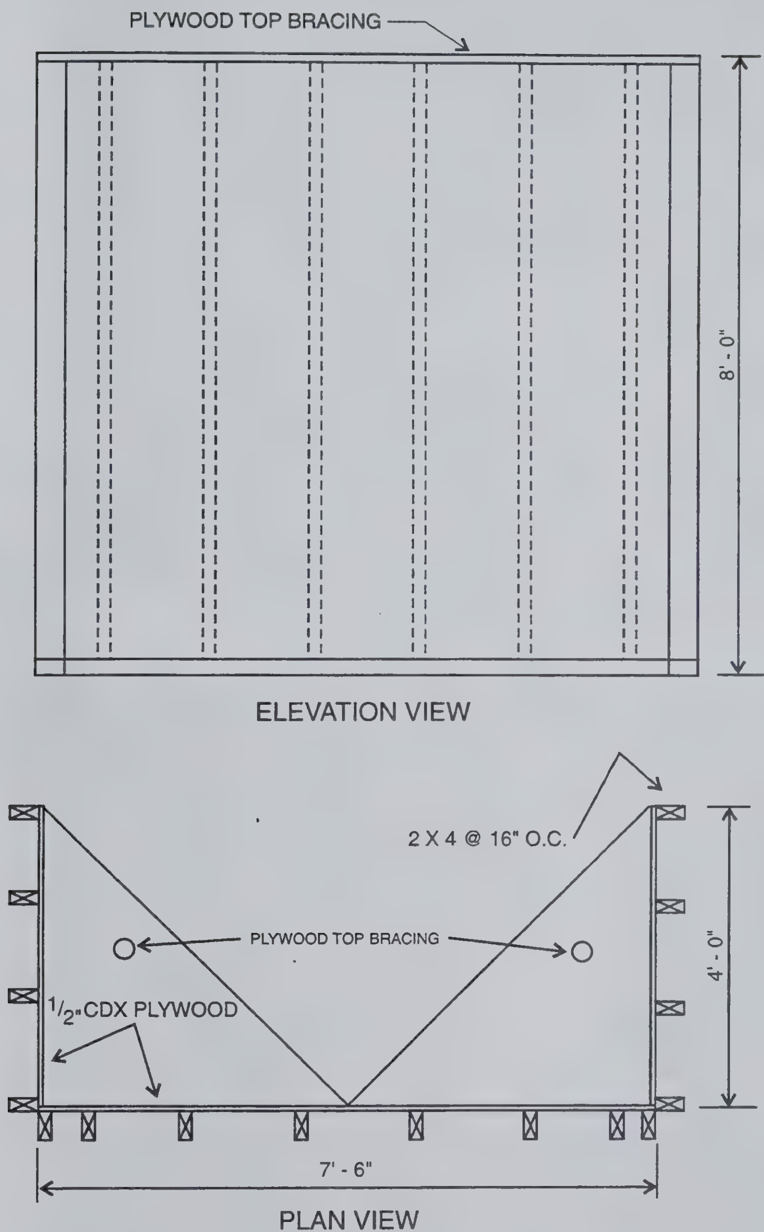


Figure 2 Three-Walled Wood Frame

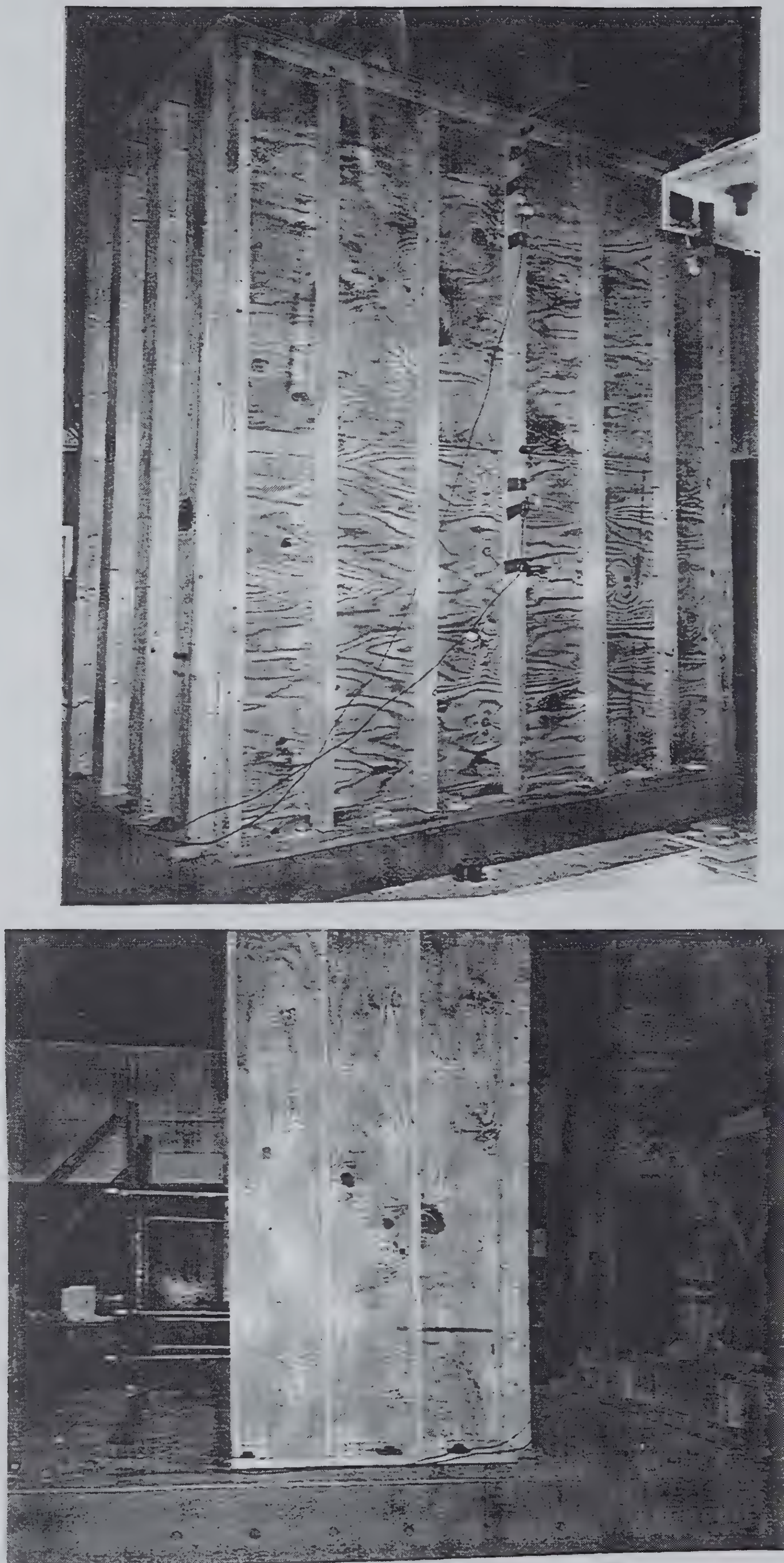


Figure 3 Photographs of Three-Walled Wood Frame

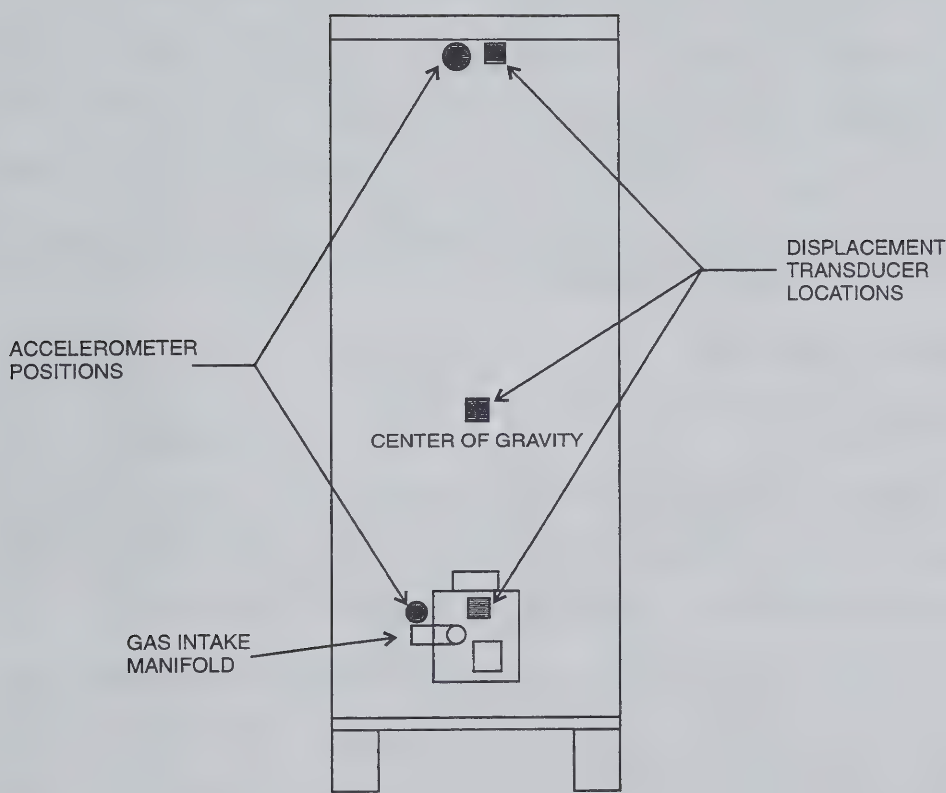


Figure 4 Placement of Accelerometers and Displacement Transducers

The torque and axial forces applied to the rigid gas pipe connection were measured by a specially made load cell. The load cell was made from a length of black iron pipe (typical for gas line construction) with strain gauges strategically placed to measure the torque and axial forces applied to the pipe connection. The four strain gauges used to measure axial force were placed in pairs (180 degrees apart) along the longitudinal axis of the pipe. The four strain gauges used for measuring toque consisted of two pairs of gauges that were 45 degrees apart. A layout of the load cell and strain gauge placement is illustrated in Figure 5.

2.1.4 Input Accelerations

Several types of input accelerations from records of past earthquakes were used in the test program. The two earthquake records used exclusively were Taft (1952, lateral component = N21E) and El Centro (1940, lateral component = S00E). Several levels of input accelerations were used for each earthquake record. The levels used for Taft were 100%, 200%, and 300% of the original recorded accelerations. The levels used for El Centro were 50%, 100%, and 150%. The accelerograms for both earthquakes and the varying strengths are shown in Figure 6. The two earthquake records at the various levels represent a wide range of frequencies and accelerations in order to adequately simulate seismic conditions for the test program.

2.2 Restraint Methods

2.2.1 Tape Method

The Tape Method is a restraint system which was devised by EQE and approved by the California Office of the State Architect (EQE Inc., 1987). The system involves a very simple installation process, and is outlined below. A copy of the pamphlet which details the method and instructions on assemblage is provided in Appendix A.

The Tape Method involves the use of ordinary galvanized plumbers' tape. Other common names for the same product are hanger iron, plumbers strap, perforated metal strap, etc. Plumbers' tape is manufactured in many widths and thicknesses but the size used in this method is exclusively 3/4in. X 24 gauge. This size of the plumbers' tape has been tested for material properties that are necessary for construction using this restraint method. Other materials necessary for construction include ordinary 1/4in. carriage bolts with nuts and 1/4in. X 3.5in. lag screws with washers. All the materials involved are inexpensive and easily purchased at any hardware store.

The installation of the tape method of restraining water heaters is a relativity simple process. The system can be used for either straight wall application or corner placement. For either of the applications the installation is the same. First, the homeowner unwraps a roll of plumbers' tape around the top front of the water heater (see Figures 7 and 9) and fasten the ends of the tape to studs with lag screws. Repeat this procedure except unwrap the tape around the top backside of the water heater and fasten to the studs. Repeat the previous two steps with tape wrapped around the front

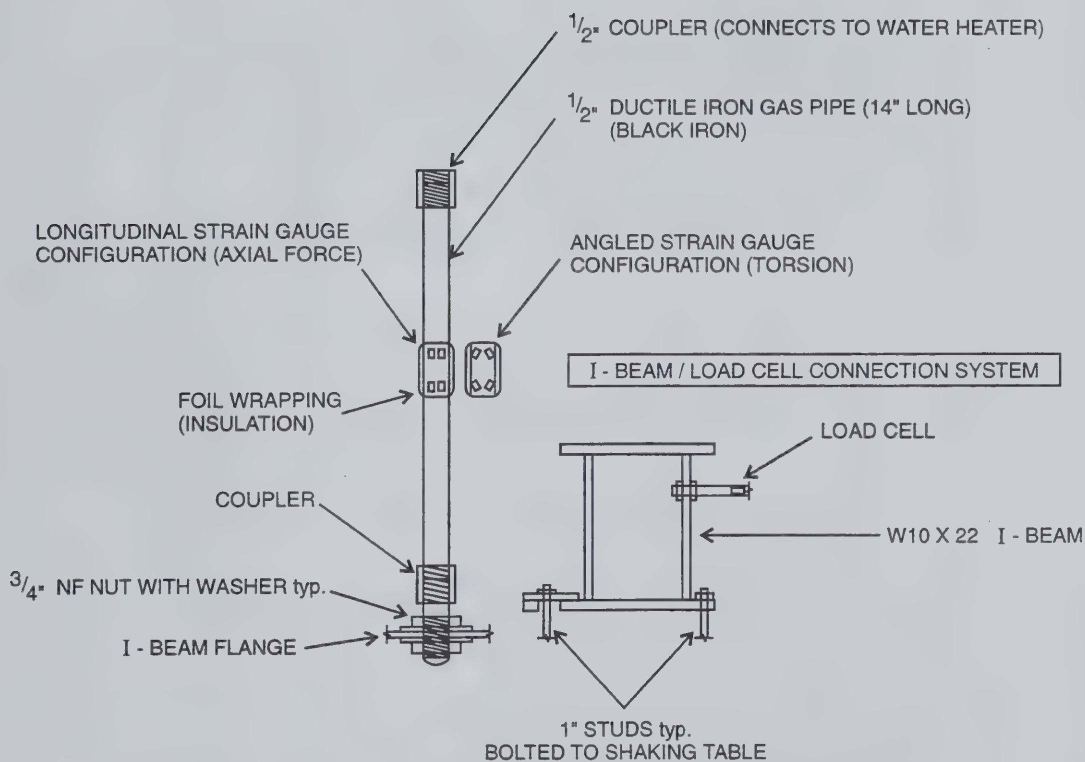
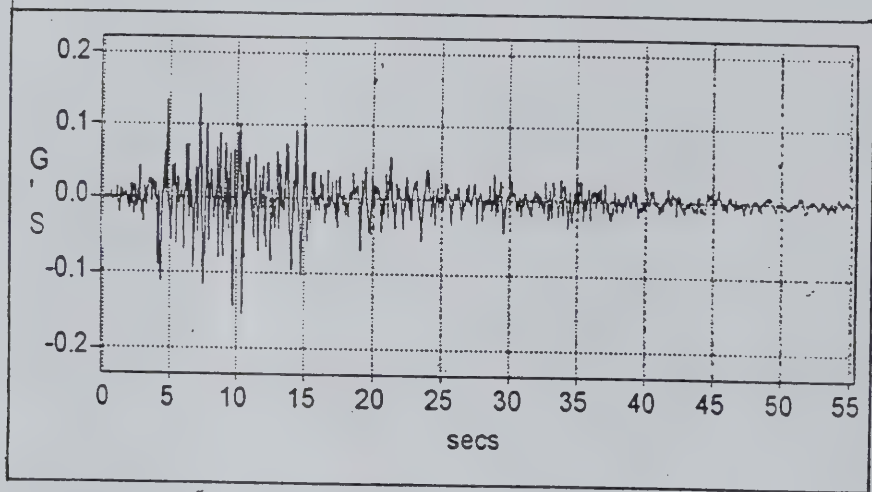


Figure 5 Load Cell Schematic

Input

Taft : Maximum Ground Acceleration = .156g

Input Levels - 100%, 200%, 300%



El Centro : Maximum Ground Acceleration = .34g

Input Levels - 50%, 100%, 150%

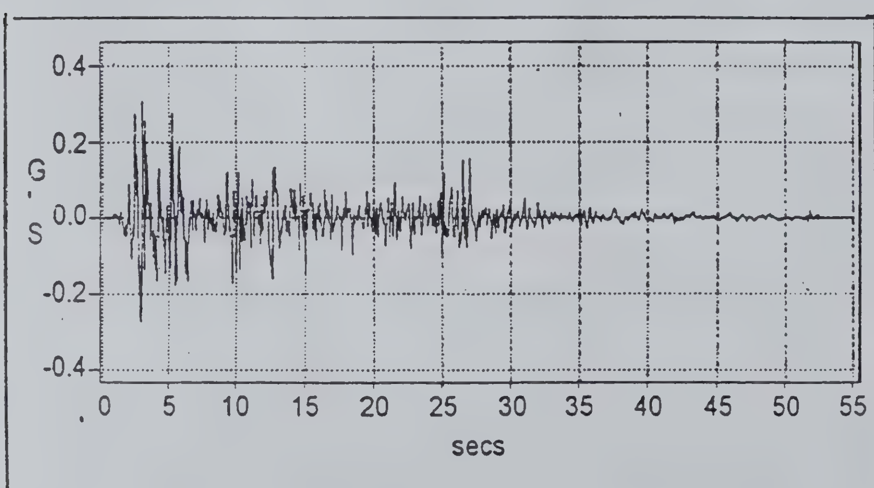


Figure 6 Accelerograms of Taft and El Centro Earthquakes

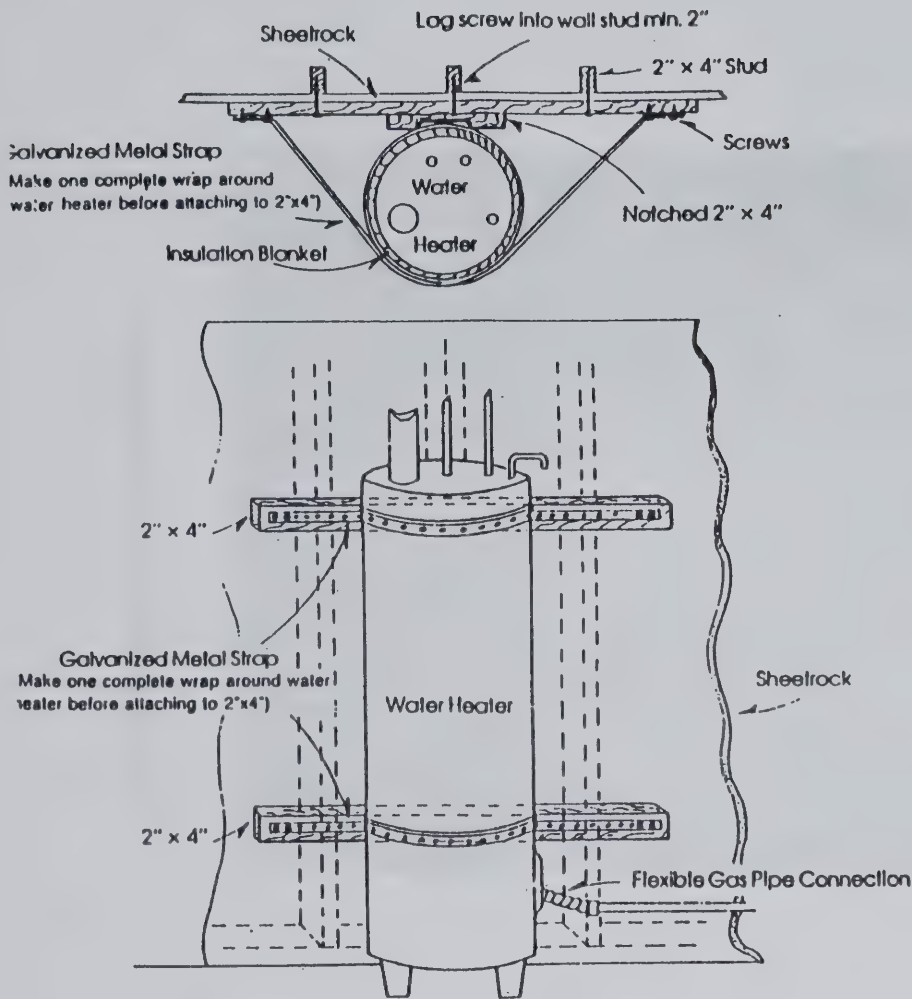


Figure 7 Diagram of Tape Method (EQE Inc., 1987)

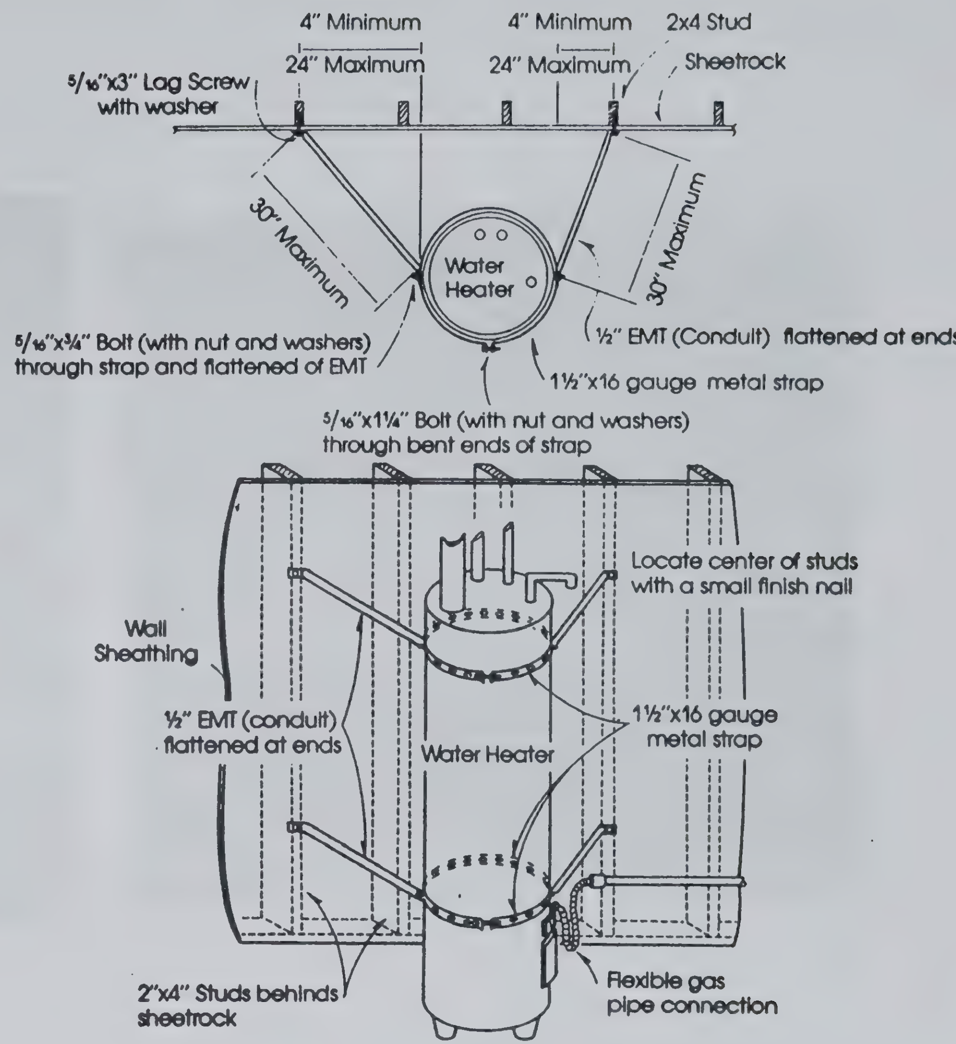


Figure 8 Diagram of Conduit Method (EQE Inc., 1987)

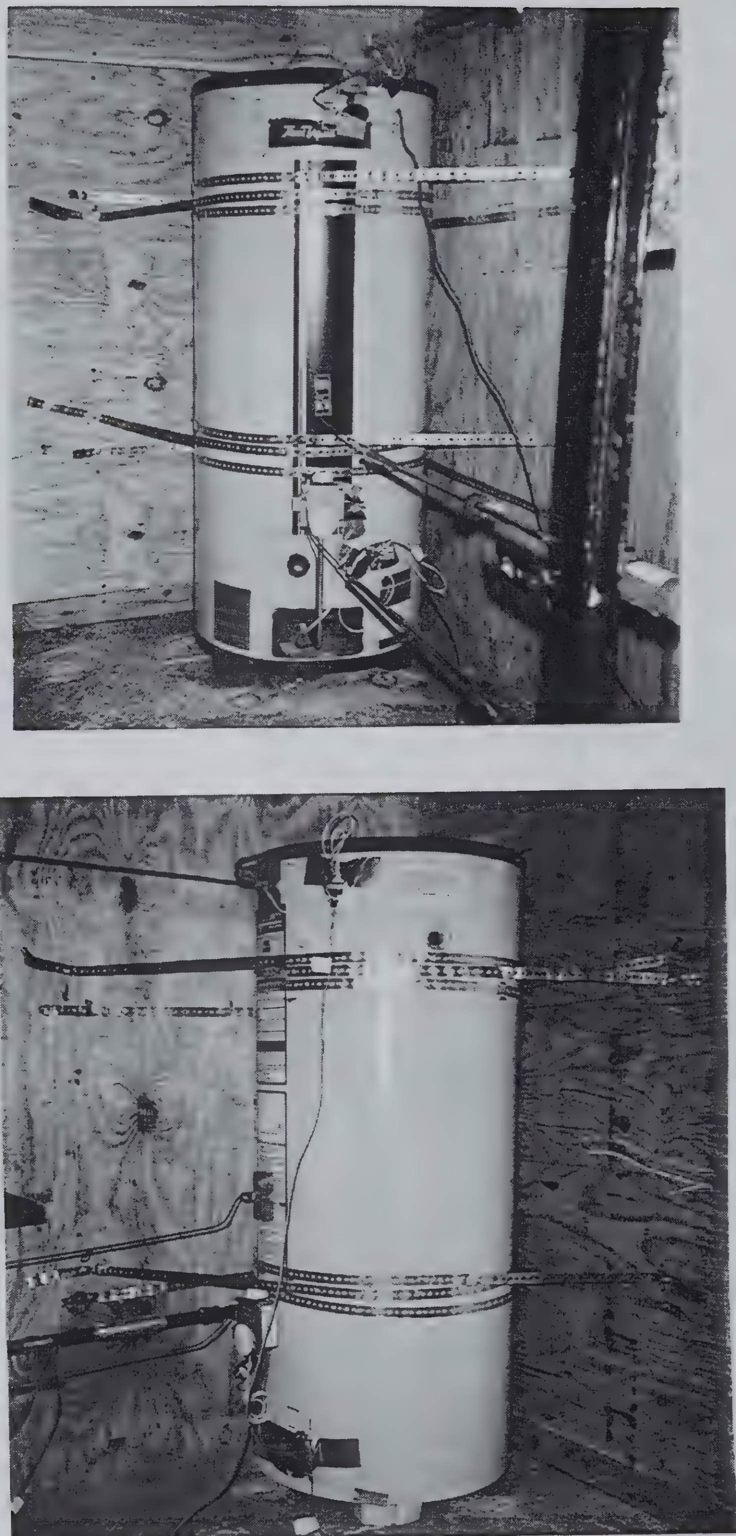


Figure 9 Tape Method

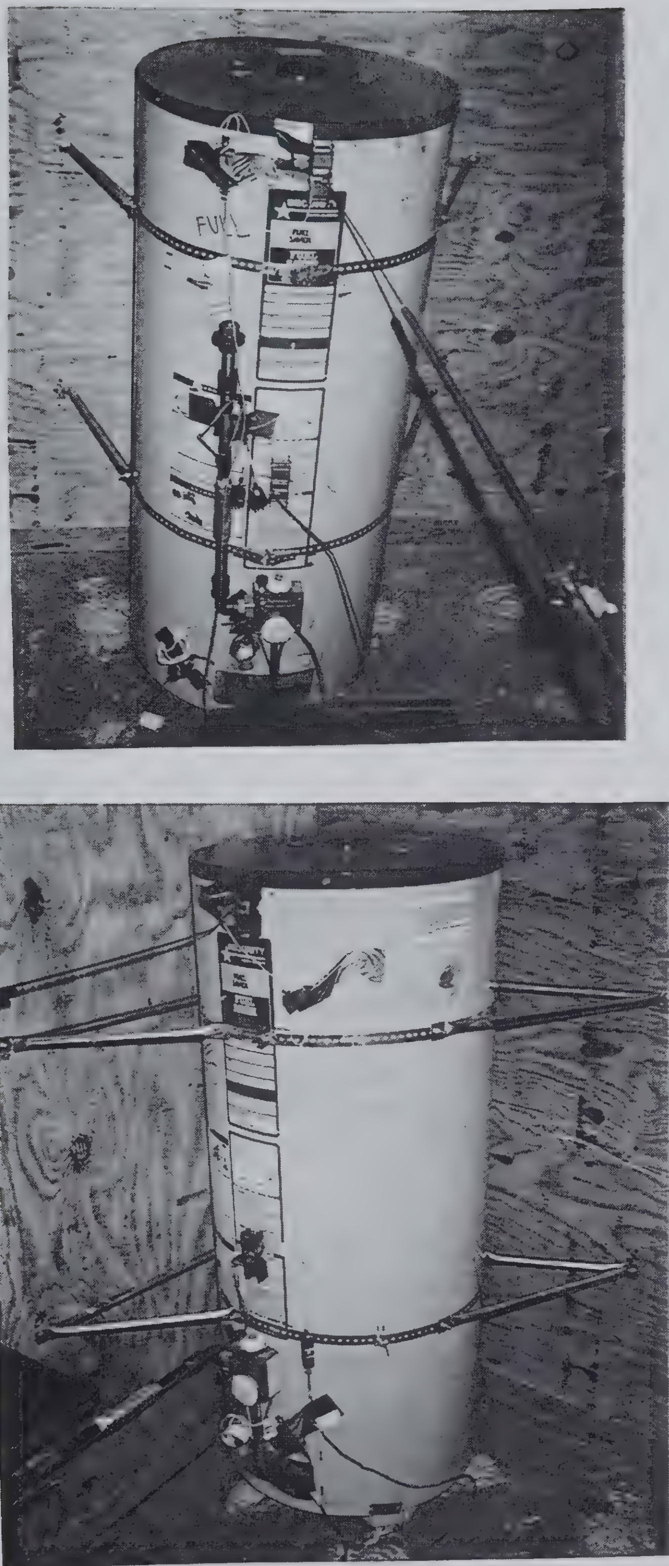


Figure 10 Conduit Method

and backsides of the bottom of the water heater. The approximate distances for tape placement is detailed in Appendix A.

2.2.2 Conduit Method

The Conduit Method is another restraint system that was first proposed by EQE and approved by the California Office of the State Architect (EQE Inc., 1987). This system is more complicated to install than the tape method. The materials involved are 1/2in. diameter EMT tubing (electrical conduit), plumbers' tape, 1/4in. bolts, and 1/4in. lag screws. The conduit is standard thin walled electrical tubing.

A brief overview of the installation process follows and a copy of the pamphlet distributed by the California Office of the State Architect are provided in Appendix B. To start, the homeowner must wrap the plumbers' tape around the water heater at the designated heights. A schematic of the restraint method and a photograph of its installation are shown in Figures 8 and 10. The homeowner must then cut the electrical conduit to the measured distance and crimp the ends. A hole should be drilled to fit the conduit to the plumbers' tape with a 1/4in. carriage bolt. Another hole must be drilled on the other crimped end of the conduit and lined up with a stud. This cutting, measuring, drilling, and lining up must be repeated for each leg of the bracing system. For corner placement, eight pieces of conduit are required and, for straight wall placement, four pieces are necessary. This method of restraining water heaters is somewhat labor intensive. The cost of materials is again inexpensive and easily found at any hardware store.

2.2.3 Manufacturers' Methods

There are two methods produced by private manufacturers that were tested. The first one, designated as Method A, has the seal of approval by the California Office of the State Architect. The second method is referred to as Method B. This method, however, has not yet been approved by the California Office of the State Architect. The following is a brief overview of the installation process for the two manufactured restraint systems.

Method A: It is the first of two restraint methods developed by a manufacturer. This restraint method has been approved by the California Office of the State Architect. A list of materials needed for this installation is as follows: 4 - 18 gauge galvanized metal straps, 2 tension buckles. 4 ¼" x 5" lag screws and washers.

The installation begins with measuring 9" down from the top of the heater and 4" above the gas intake housing. The homeowner then measures the same distances from top and bottom on the nearest wall studs (or to concrete wall) in order to drill the holes necessary for the lag screws. One end of each of the straps is then screwed into the wall. The two top straps are then wrapped around the water heater and attached to a tension buckle. The straps are then tightened and the buckle locked in place. The procedure is then repeated for the bottom two straps.

Method A, as illustrated in Figure 11, is easily installed but relies on the fact that the water heater is close (within a few inches) to the anchoring wall.

Method B: The second manufacturers' method that was tested is designated as Method B. Method B has not been approved by the California Office of the State Architect. The materials involved in the installation process are 1-20 gauge steel strap, 2 steel anchor brackets, 3/8" x 3" lag screws and ¼" carriage bolts.

The steps for installation begin with measuring down one third the height of the heater from the top (see Figure 12). This is the position of the strap across the heater. Next, the holes corresponding to the strap height are drilled and the steel brackets are screwed into the wall. The strap is then installed and tightened down by wrapping the ends of the strap around and bolting them together.

Method B is again simple to install but the pre-drilled holes in the straps used for tightening didn't always match up and subsequently the strap was loosely applied.

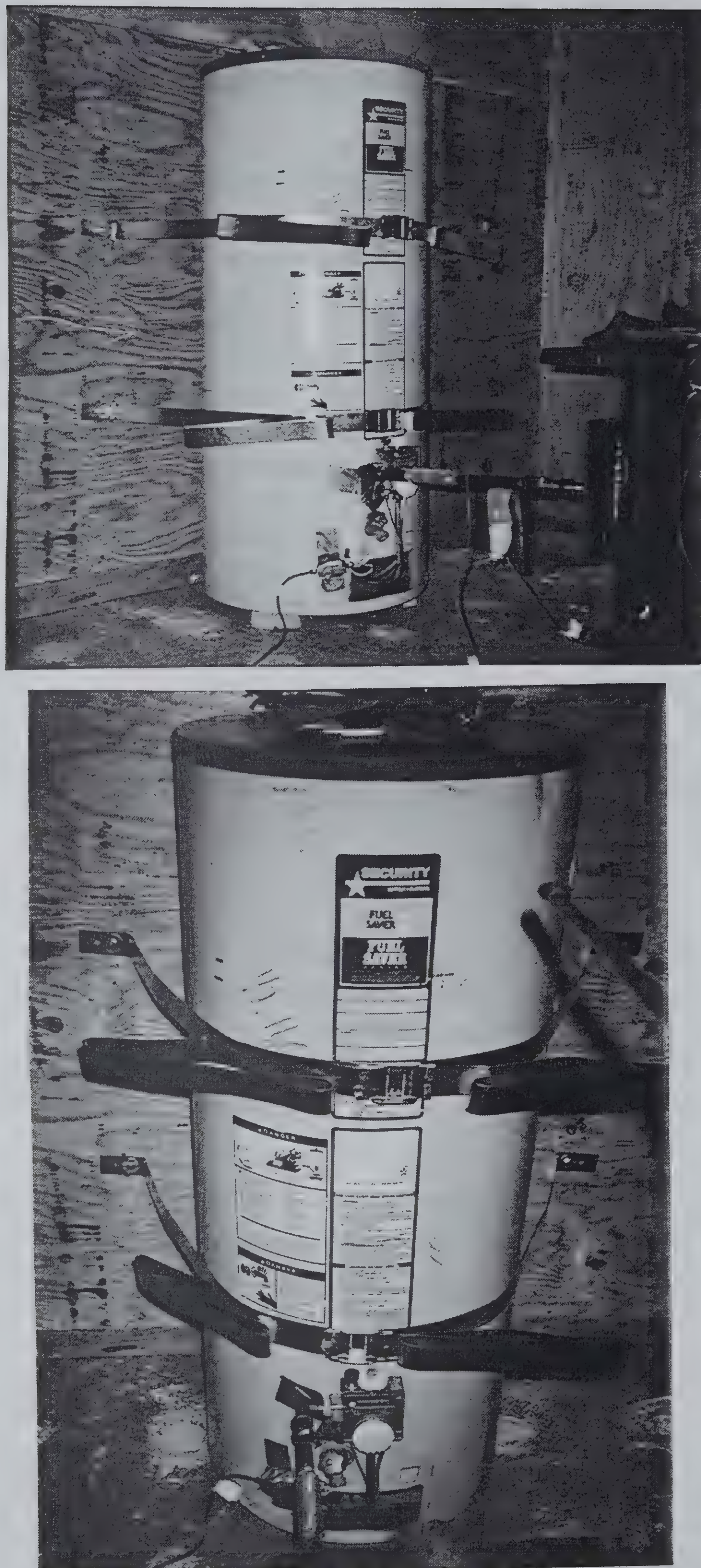


Figure 11 Method A

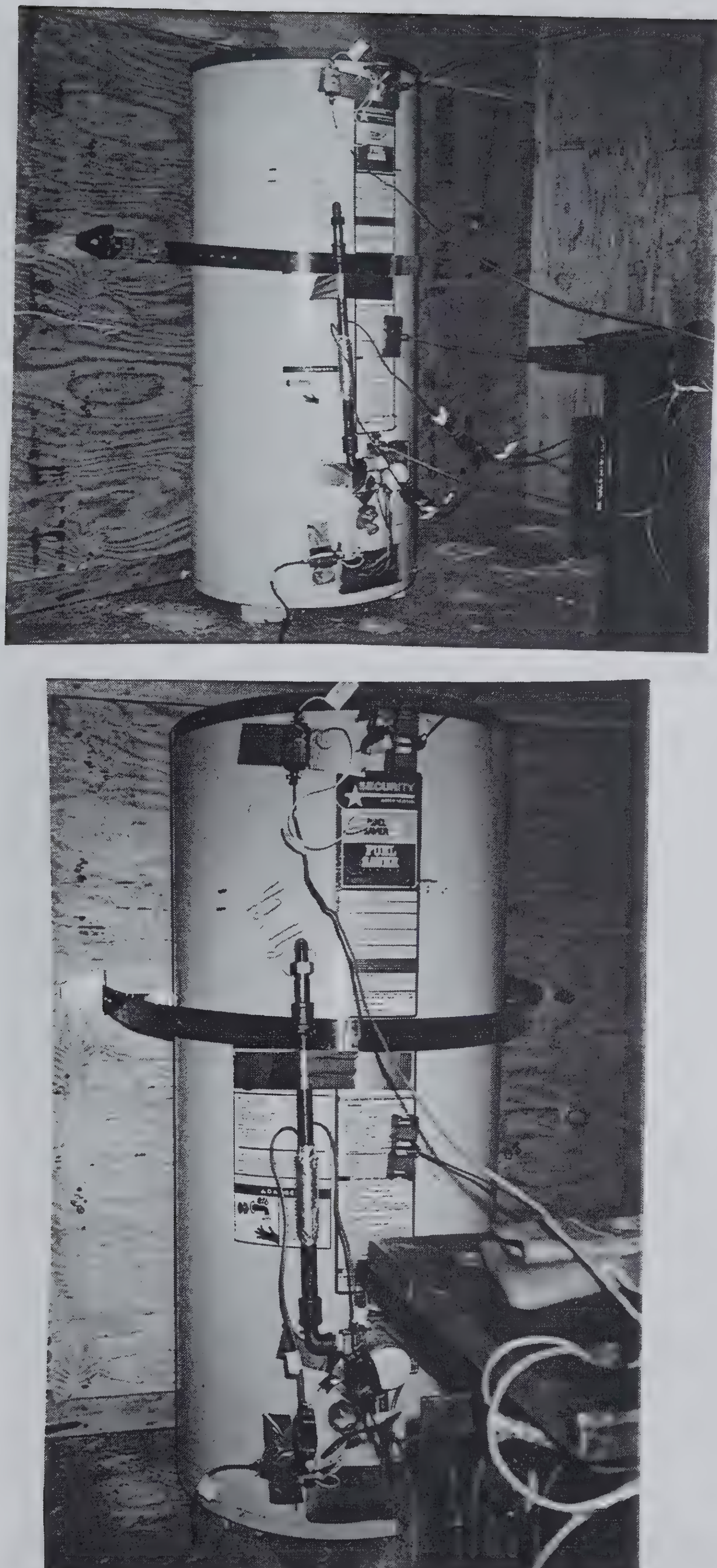


Figure 12 Method B

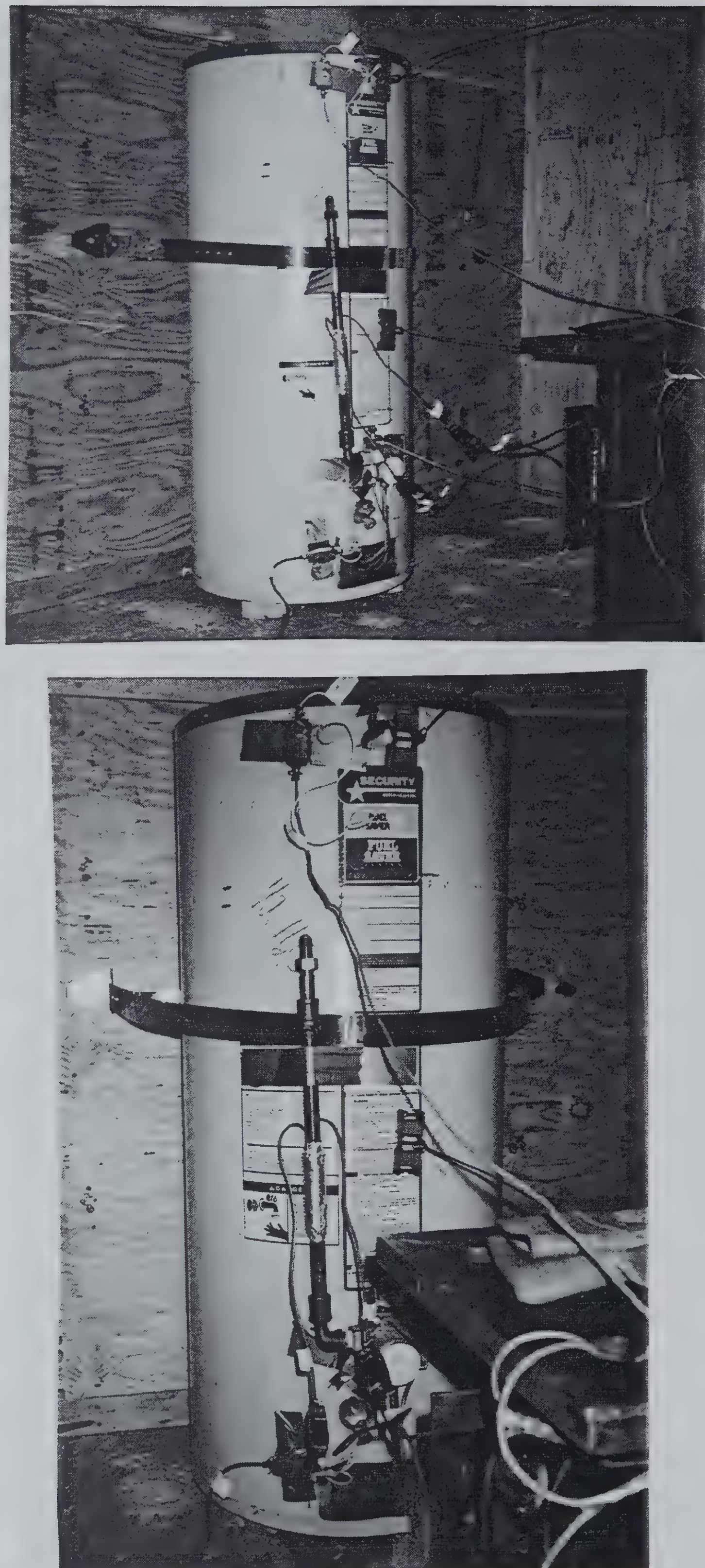


Figure 12 Method B

SECTION 3

PERFORMANCE OF RESTRAINTS

3.1 Computer Analysis

The first stage of testing is always the computer analysis phase. In this project a computer program was written to incorporate the accelerations of an actual event and transpose those motions into a simulated response of a restrained water heater. The program calls up acceleration time histories and through a series of equation estimates the motion of the water heater. The program will then output information such as maximum acceleration, maximum displacement, and tension in the restraining materials. A brief overview of the program is described below with sample input and output files to follow. A listing of the computer program is provided in Appendix B.

In order to start the program the operator must create an input file with the desired values of the following variables:

1) Initial restraint (strap, conduit, plumbers' tape, etc.) tension
2) Restraint spring constant (modulus of elasticity)
3) Restraint inclination angle
4) Height of the water heater from floor (centroid)
5) Weight of the water heater
6) Coulomb friction coefficient
7) Accelerogram time interval
8) Total number of points in accelerogram

Once the input file has been created the program can be run. The initial sequence the program follows is to read the input file values, make the necessary unit conversions, and initialize the output variables. In the next step the program reads the acceleration time history and calls up a subroutine, which in turn calculates the restraint extension and the horizontal forces (see Figure 13). From the determination of these forces and the simple integration of the acceleration (using Simpson's Rule) the velocity and displacements can be calculated. The dynamic forces in the restraints, acceleration, and displacement responses are then written to the media desired. The program can simulate a response given any restraint configuration or input event. A sample of the output is illustrated in Figures 14-17.

The output is then analyzed to evaluate the integrity of the restraint components. The forces generated by the simulated earthquake are used in determining the overall performance of the restraint method. The acceleration and displacement time histories are analyzed to foresee any possible problems before actual physical testing occurs.

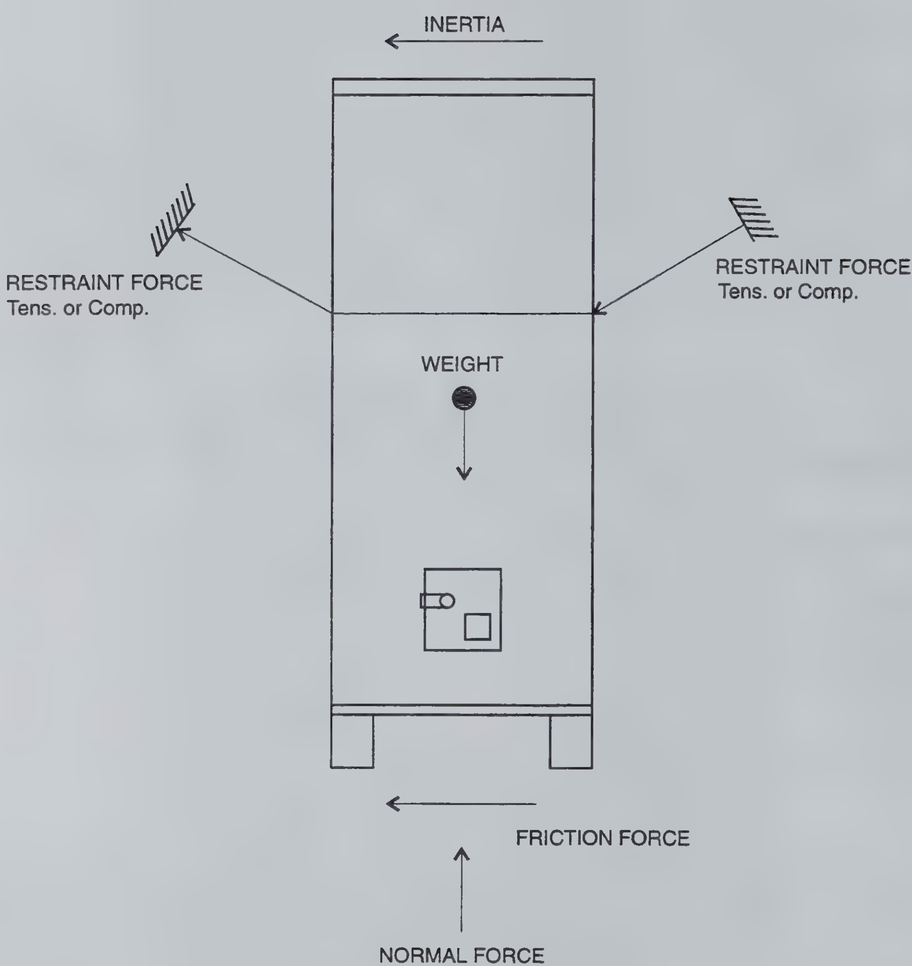


Figure 13 Summary of Forces

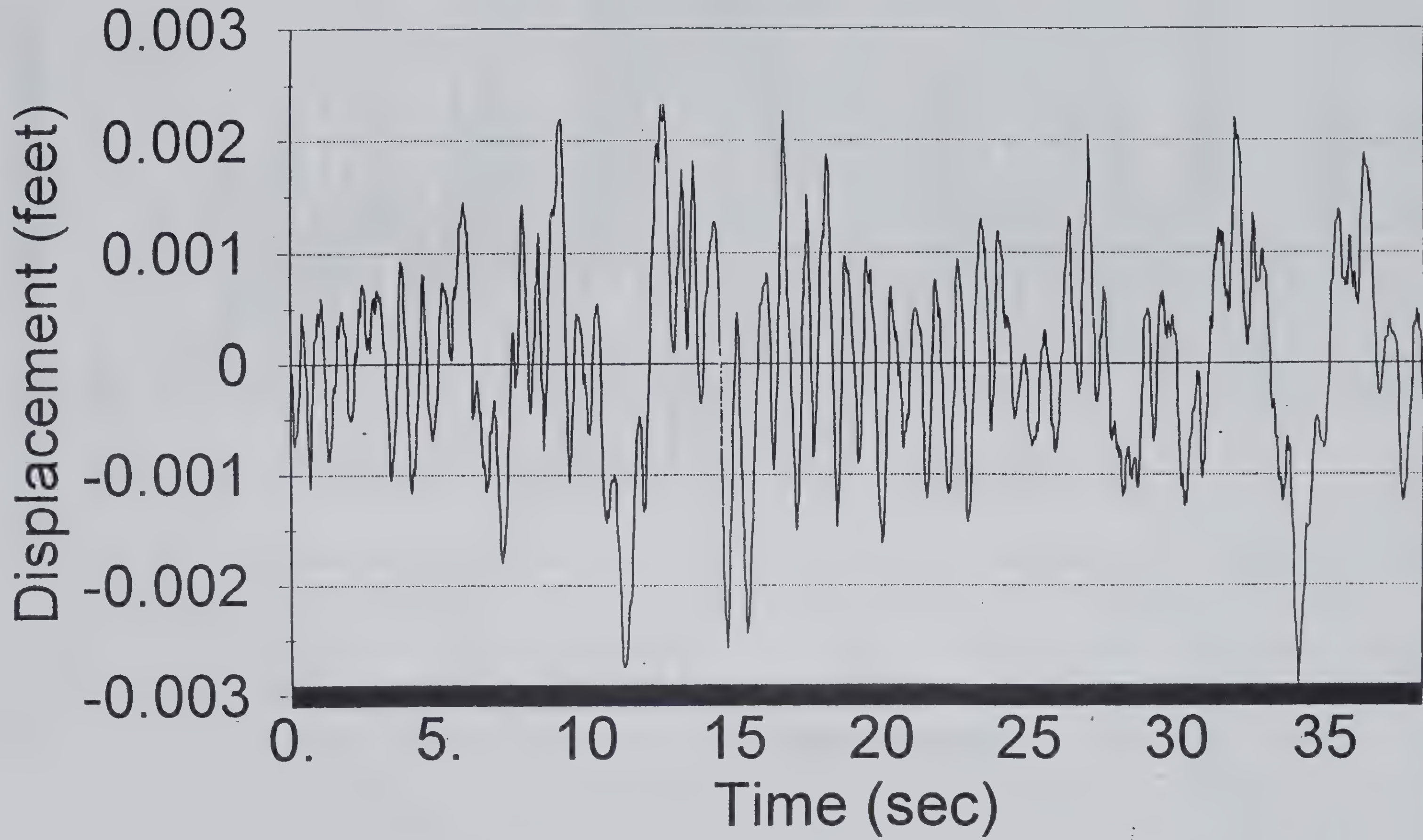


Figure 14 Sample Output - 100% Taft - Displacment

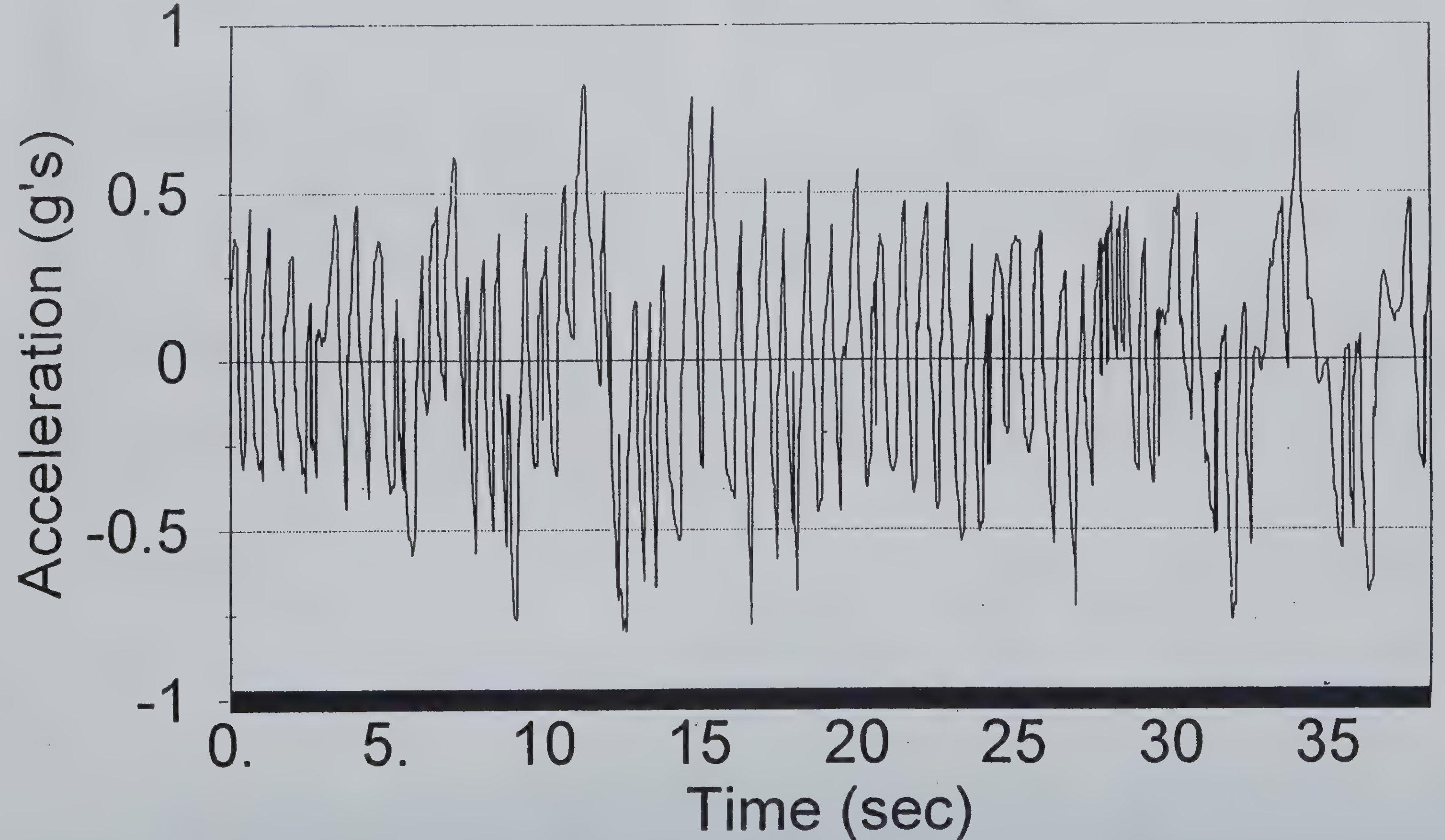


Figure 15 Sample Output - 100% Taft - Acceleration

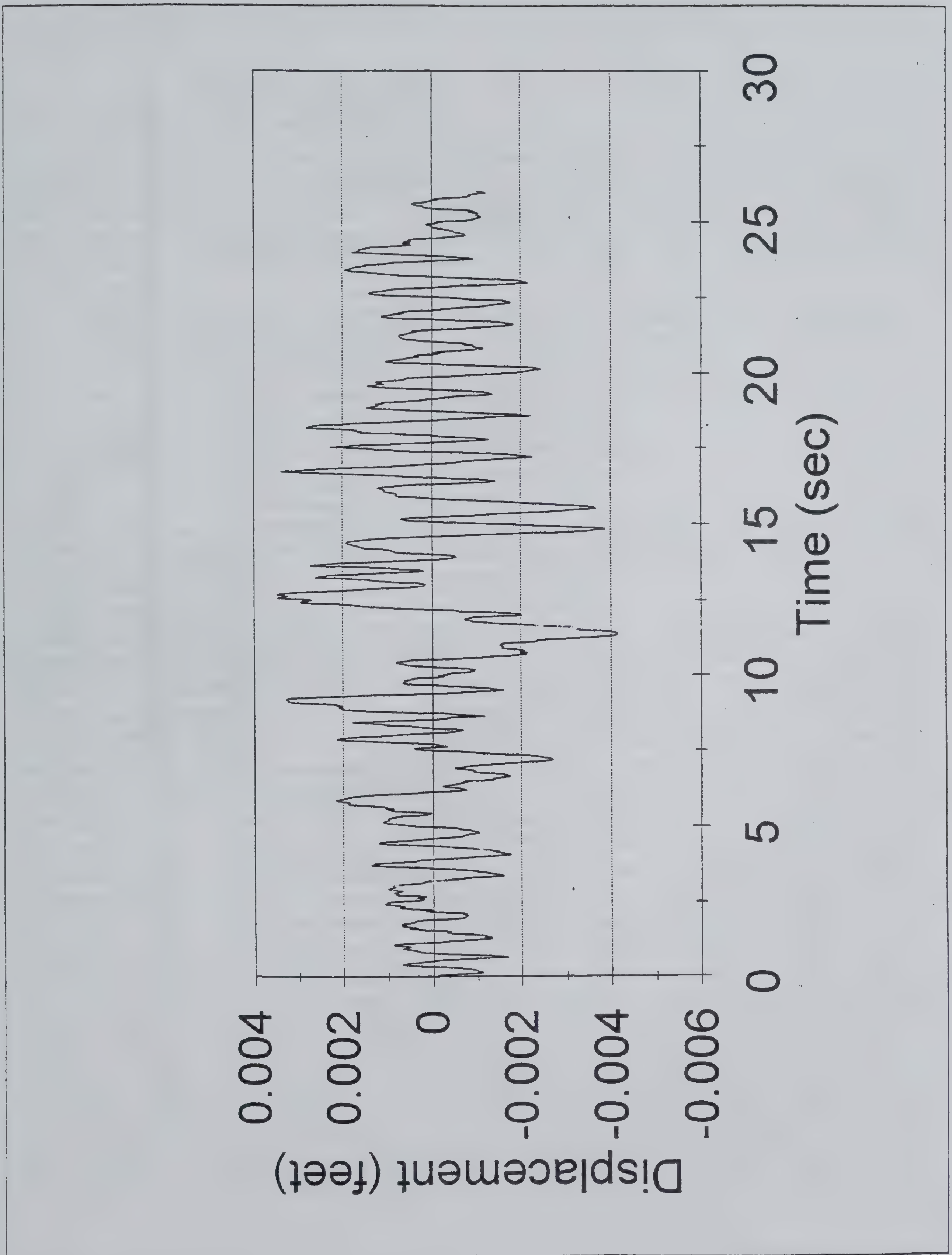


Figure 16 Sample Output - 200% Taft - Displacment

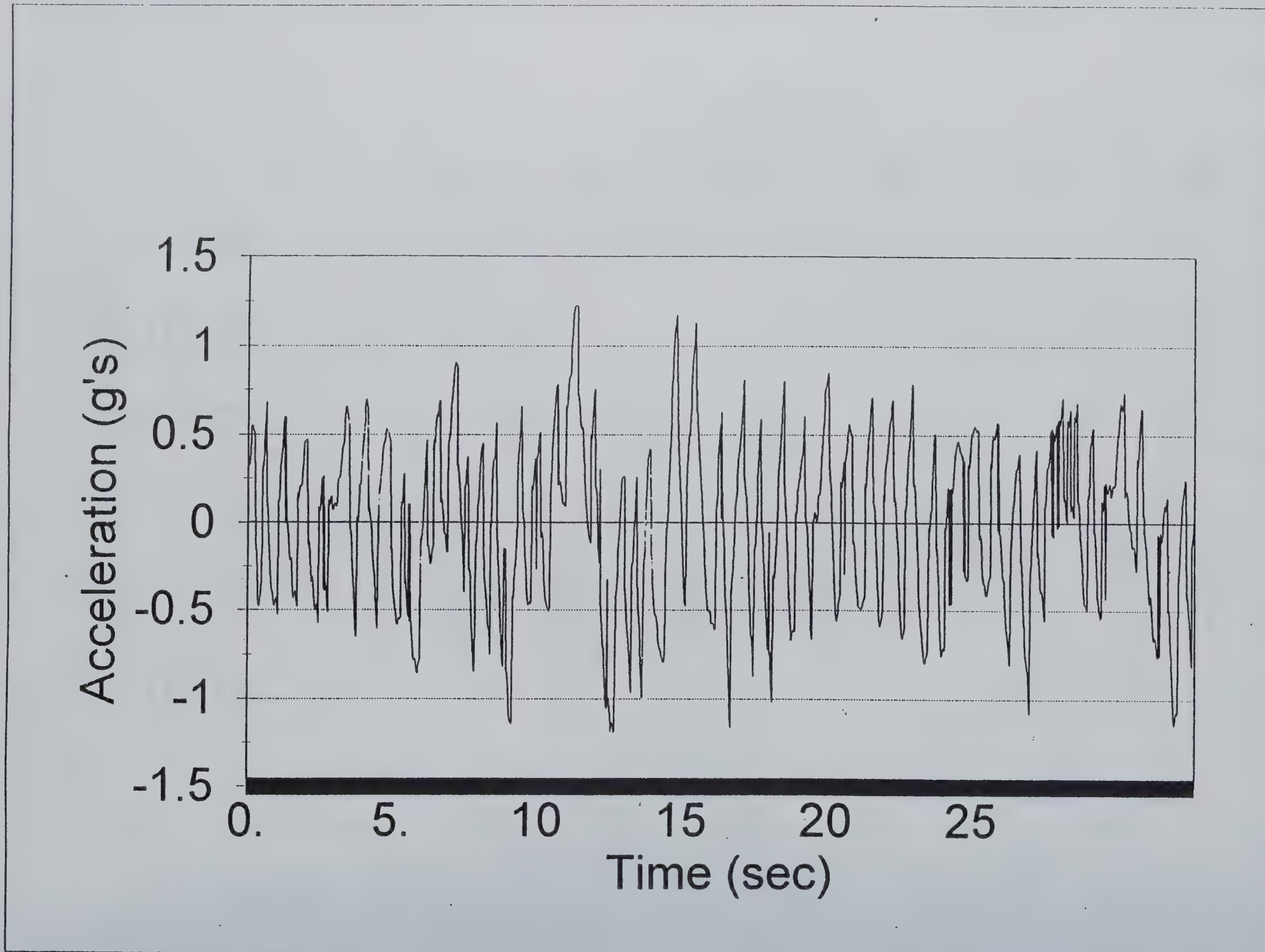


Figure 17 Sample Output - 200% Taft - Acceleration

After the physical model has been tested the computer results are used as a comparative tool.

3.2 Testing of Physical Model

The experiments performed on the physical model were to be the most informative portion of this project. The make-up of the model had to simulate the reality faced by any homeowner trying to restrain his/her water heater. This notion posed a unique challenge in attempting to imitate the conditions under which an ordinary water heater is used in the household. For example, several of the problems encountered were:

- How is the water heater connected to the gas and water distribution system?
- Do these pipe fixtures provide any rigidity against motion?
- Do the pipe fixtures have a breaking point that need be identified?
- What is the best structure to simulate the average basement or garage?
- How rigid and/or flexible should the structure be?
- What size and form of water heater should be used?
- Are there differences between water heater models?

There were many other questions that needed to be addressed, but these are just examples that needed to be answered before the experimental stage could begin.

Many of the questions stated above were answered via contacting water heater manufacturers and distributors. The question of "what size and form should the water heater be " was answered quite simply. Residential water heaters have generally between 40 and 50-gallon capacities and only vary slightly in size. The average water heater stands between 4 and 5 feet in height and ranges from 16 to 20 inches in diameter. Manufacturers of water heaters unanimously agreed that the market is competitive and any unnecessary "frills" are unprofitable. Therefore, water heaters are generally produced with little variance in physical make-up and only small differences in energy efficiency. Hence, most residential water heaters are generic with only minor differences, which came in the style of support ("feet") and type of insulation (fiberglass or packed foam). The insulation differences were of little importance in the overall experiment. Although it may be noted that the packed foam insulation did serve to aid the outer steel jacket of the water heater to hold its integrity (not crush in) when the restraints were tightened down. The supports or feet of the water heater were of more significance. It was found that there are three different styles of support: 1) thin gauge metal angles attached to the base in a square pattern, 2) a folded thin gauge metal support that went around the perimeter of the water heater base, and the most common, 3) thin gauge metal folded over and attached to the base in triangular pattern. Some manufacturers produced water heater models that had no supporting legs and left the consumer with the burden of building an elevated base. These models were disregarded in the overall analysis. It should be noted that in all building codes it is stated that the water heater must be elevated off the ground for safety. This is perhaps the reason the unsupported water heaters are rare. The third type of support, folded

metal legs in triangular pattern, is the most common and was thereby given the most attention.

The restraint systems needed to be attached to a simulated structure. That structure needed to be rigid enough to sustain the accelerations of the shaking table and to accept the forces generated by the restraints. Through research of common construction practice and referral to several publications by EQE (EQE Inc., 1987) and the California Office of the State Architect (OSA, 1992), it was found that a stud wall was the most common placement occurrence of water heater restraint methods. Stipulations for concrete anchorage are given in the pamphlets written by both organizations. There is no great difference in a concrete wall and stud wall in restraint system anchorage as long as there is proper attachment. With these facts in mind the choice of using a stud wall with plywood sheathing was chosen as the structure to which the water heaters in the test program were anchored.

Careful considerations were given to simulate the performance of pipe connections under seismic conditions. The gas intake on all water heaters is standard and so is the piping material. It was devised in the test program to use an actual piece of ductile iron pipe (standard for gas lines) as a load cell to evaluate the forces generated in the pipe and its connections due to earthquake motion. The load cell was produced (as described in the Introduction) using strain gauges oriented to measure the resulting axial force and torsion caused by the motion of the water heater in response to the earthquake event. The load cell was rigidly connected to a base that was separate from the framed structure but anchored to the shaking table. This method was used because it closely resembles the conditions found in the ordinary household. The real household conditions are such that the gas pipeline connects to a meter box outside of the home and then proceeds into the house towards the water heater. Along the gas line path there are more than likely several joints and elbow fixtures. These fixtures (90-degree elbow and coupler joint) were also included in the make-up of the load cell to accurately simulate real life conditions. Once the experimental setup was devised, the next step was to attain testing specimens. In order to simulate the average home conditions, used and slightly used water heaters were tested. The heaters were graciously donated by the local plumbing suppliers. The effect of testing used water heaters instead of new heaters was again to more accurately simulate realistic household conditions. The used water heaters were all structurally sound but were discarded because of mechanical flaws.

A testing schedule was the first step in the experimental process. It was agreed upon that three different weight variations were to be tested; empty tank, half-full tank, and full tank. The water heaters were weighted down with lightweight sand instead of water. The sand was used to prevent damage to the experimental facility and instrumentation in the event of an accidental spill or leak. The sloshing effect of the water inside the tank was deemed negligible. Pressure within the water heater was also not considered. The testing sequence that was followed was developed to run the multitude of tests in the most efficient manner as possible. The following sequence of tests, as seen in Table 3, was performed. It should be noted that all the following tests were conducted twice,

once with the load cell intact and again without the load cell connected. This was done to illustrate the two conditions that could be encountered in the home. The first condition corresponds to the case where the water heater has rigid pipe connections right up to the gas intake and the other condition approximates a freer water heater that is connected by flexible tubing. The first condition obviously allows for some resistance to movement while the second allows for freedom of movement. Both cases needed to be recognized and tested.

Table 3 : Testing Sequence

Restraint Method	Placement	Weight	Earthquake	Level
Tape Method	**Straight Wall**	**empty**	**Taft**	**200%, 300%**
			El Centro	**100%, 150%**
	Straight Wall	**half full**	**Taft**	**200%, 300%**
			El Centro	**100%, 150%**
	Straight Wall	**full**	**Taft**	**200%, 300%**
			El Centro	**100%, 150%**
	Corner	**half full**	**Taft**	**100%, 200%**
			El Centro	**100%**
	Corner	**full**	**Taft**	**200%, 300%**
			El Centro	**100%, 150%**
Conduit Method	**Straight Wall**	**empty**	**Taft**	**200%, 300%**
			El Centro	**100%, 150%**
	Straight Wall	**half full**	**Taft**	**200%, 300%**
			El Centro	**100%, 150%**
	Straight Wall	**full**	**Taft**	**200%, 300%**
			El Centro	**100%, 150%**
	Corner	**half full**	**Taft**	**100%, 200%**
			El Centro	**100%**
	Corner	**full**	**Taft**	**200%, 300%**
			El Centro	**100%, 150%**
Method A	**Straight Wall**	**half full**	**Taft**	**100%, 200%**
			El Centro	**100%, 150%**
	Straight Wall	**full**	**Taft**	**200%, 300%**
			El Centro	**100%, 150%**
Method B	**Straight Wall**	**half full**	**Taft**	**100%, 200%**
			El Centro	**100%, 150%**
Bracket Method	**Straight Wall**	**full**	**Taft**	**200%, 300%**
*(See Sec. 5)			**El Centro**	**100%, 150%,200%**

As can be seen from the testing schedule, an emphasis was placed upon experimentation of the installation methods endorsed by the California Office of the State Architect (Tape and Conduit Methods). These methods were of concern because they have more direct impact to the general public. The two manufacturers' methods were tested less comprehensively because of shortcomings that will be discussed in Section 5. The Bracket Method was developed while the experiment was commencing. It is a method that was formulated from observations of the strengths and weaknesses of the other methods. The Bracket Method will also be discussed thoroughly in Section 5.

3.3 Summary of Experimental Results

The following tables (Tables 4-6) illustrate the peak values for the important variables. Maximum acceleration, displacement, axial force, and torque are listed below for all the tests that were completed. The maximum accelerations and maximum displacements always occurred at the top of the water heater unless otherwise noted. The maximum axial force and torque that are possible before the pipe or connection break are 900 lbs compression and 60 in-lbs of torque.

3.4 Comparison of Analytical and Experimental Results

The computer analysis performed used the Conduit Method as the model platform. The Conduit Method was chosen as the basis of the computer model because of the method's ability to withstand dynamic reversals of forces (i.e. tension and compression). The sample output which can be seen in Figure 14 utilized the input record of the Taft earthquake. As can be seen in Table 7, the computer model predicted conservatively the approximate peak accelerations of the physical model. However, the computer program did not perform as accurately when the maximum displacements were compared. This can be attributed to the difficulties in modeling the complexities involved in water heater modeling with attendant connections and contact surfaces. For example, the computer model uses the theoretical stiffness of the conduit material and does not account for the deformations inflicted upon it during the installation process (flattened, bent ends of the conduit). Furthermore, only sliding was considered in computer simulation, while tipping, jumping and other irregular movements were observed during the test sequence.

Table 4 Tape Method Results

Tape Method

	E-Quake record	Peak Table acceler. (g's)	Max. accel. top (g's)	Max. accel. bottom (g's)	Max. top displacment (in.)	Max. middle displacment (in.)	Max. bottom displacment (in.)	Max. torque (in.-lbs.)	Max. axial (lbs.)
Corner									
Full tank	200% Taft	0.35	0.7	0.45	0.31	0.25	0.25	4	110
	150% El Centro	0.6	1.4	0.8	0.8	0.45	0.5	16	310
1/2 tank	200% Taft	0.35	0.61	0.35	0.04	0.05	0.05	7	60
	100% El Centro	0.31	0.8	0.5	0.11	0.08	0.1	12	65
Straight									
Full tank	200% Taft	0.35	0.55	0.4	0.1	0.07	0.06	5	100
	150% El Centro	0.6	1.5	1.1	0.35	0.3	0.28	11	350
1/2 tank	200% Taft	0.35	0.7	0.37	0.17	0.1	0.07	4	40
	150% El Centro	0.6	1.6	1	0.4	0.28	0.2	25	100
Empty	300% Taft	0.55	1.3	0.7	0.28	0.14	0.11	7	50
	150% El Centro	0.6	2	1	0.3	0.17	0.11	13	70

Table 5 Conduit Method Results

Conduit Method

	E-Quake record	Peak Table acceler. (g's)	Max. accel. top (g's)	Max. accel. bottom (g's)	Max. top displacment (in.)	Max. middle displacment (in.)	Max. bottom displacment (in.)	Max. torque (in.-lbs.)	Max. axial (lbs.)
Corner									
Full tank	200% Taft	0.35	0.9	0.4	0.24	0.11	0.12	2	45
	150% El Centro	0.6	1.7	1	0.4	0.25	0.25	10	125
1/2 tank	200% Taft	0.35	0.6	0.3	0.16	0.09	0.09	1	25
	150% El Centro	0.59	1.5	0.9	0.2	0.15	0.15	2	65
Straight									
Full tank	200% Taft	0.35	0.55	0.35	0.07	0.03	0.03	5	180
	150% El Centro	0.6	1.5	1	0.2	0.18	0.15	11	300
1/2 tank	200% Taft	0.35	0.5	0.35	0.04	0.03	0.02	1	15
	150% El Centro	0.6	1.1	0.75	0.1	0.09	0.08	2	40
Empty	300% Taft	0.55	0.6	0.45	0.05	0.03	0.03	3	20
	150% El Centro	0.6	1	0.7	0.08	0.06	0.05	6	30

Table 6 Manufacturers Methods Results

Manufacturers Methods

	E-Quake record	Peak Table acceler. (g's)	Max. accel. top (g's)	Max. accel. bottom (g's)	Max. top displacment (in.)	Max. middle displacment (in.)	Max. bottom displacment (in.)	Max. torque (in.-lbs.)	Max. axial (lbs.)
Method A									
Full tank	100% El Centro	0.34	0.9	0.65	1.15	1.15	1.15	15	195
	150% El Centro	0.6	3	1.95	1.5	1.5	1.5	60	350
1/2 tank	200% Taft	0.35	1.7	0.65	0.42	0.4	0.45	3	60
	150% El Centro	0.6	3.1	2.4	1.3	0.8	0.52	13	300
Method B									
1/2 tank	100% Taft	0.156	0.4	0.2	0.04	0.06	0.07	2	35
	200% Taft	0.35	1.1	0.6	0.6	0.6	0.62	6	75

Bracket Method

	E-Quake record	Peak Table acceler. (g's)	Max. accel. top (g's)	Max. accel. bottom (g's)	Max. top displacment (in.)	Max. middle displacment (in.)	Max. bottom displacment (in.)	Max. torque (in.-lbs.)	Max. axial (lbs.)
Full tank	200% Taft	0.34	0.42	0.4	0.045	0.04	0.038	3	75
	300% Taft	0.59	0.7	0.55	0.08	0.06	0.06	3.5	115
	150% El Centro	0.6	0.75	0.6	0.1	0.09	0.07	5	130
	200% El Centro	0.86	1.1	0.8	0.16	0.11	0.1	8	165

Table 7   Comparison of Results - Conduit Method

	Computer Analysis	Experiment
Max. Acceleration (top)	**1.2 g**	**.9 g**
Max. Displacement (top)	**.05 in**	**.24 in.**

SECTION 4

GAS SHUT-OFF VALVES

4.1 Overview

The two major means of fire mitigation in regard to water heaters are 1) restraint measures and 2) gas shut-off valves or excessive flow valves. This section will concentrate on the latter mitigation measure. Although no testing of gas shut-off valves took place in this research program, this section provides a synopsis of recent research focusing on dynamic testing of gas shut-off valves.

To date, there are many types of automatic gas shut-off valves and they are used quite extensively in industrial safety applications. The valves used in these applications are on high-pressure gas lines and require high pressure actuated shut-off mechanisms. Until now the need for a low pressure gas line shut-off valve has not been necessary. Therefore, the market does not readily provide low pressure, household use valves because of the lack of demand. Subsequently, little research has been performed on the low-pressure gas shut-off alternative. There are limited low-pressure valves available commercially but they will remain costly until the supply catches up to the demand.

Currently there is litigation pending approval in Los Angeles County, California, to require the addition of an automatic gas shut-off valve to every home and business (Koenenn, 1996). This is being met with much scrutiny because of the massive expense involved; although this may be a step in the right direction because a gas shut-off valve may be the best measure against possible earthquake attenuated fire propagation.

4.2 Test Results

In a recent study performed by Agbabian Associates (Agbabian Associates, 1995) for ASCE, fifteen gas valves from six different manufacturers were dynamically tested. The tests included actuation in three different axes (longitudinal, transverse, and vertical) and at different frequencies. The criteria for testing were as follows:

1) ANSI Z21 tests sensors at three frequencies (1Hz, 2.5 Hz, and 10 Hz). What is the actual range of performance?

2) Do some valves have different response in one axes than the other?

3) Could valves that meet the existing standard fail to trigger in a typical earthquake?

4) Are the valves robust enough to survive very strong shaking of a near-field event with magnitude greater than 7?

With these criteria in mind the researchers tested the valves at specific frequencies and also used the records of two actual earthquake events: 1) Northridge - January 17,1994 and 2) Landers - June 28,1992. Both earthquakes exhibit a broad range of frequency content and have significant peak ground accelerations (Northridge - .493g and Landers - .859g).

Conclusions reached following an extensive testing program include the following:

1. It is possible that a valve can meet the current ANSI Z21 standard and still does not perform its intended function in a realistic earthquake.

2. Valves that meet the new standards generally trigger on damaging earthquakes, but not as sensitive to spurious, low level motion.

3. Six out of the fifteen valves tested meet the new requirements. Based on these results, it is believed that meeting the new standard will not be too difficult for valve suppliers.

4. A new testing standard was proposed, which more strictly defines the “must actuate” region and addresses a gap in the previous standard between 2.5 and 10 Hz.

5. Nine out of the fifteen valves tested were found to be inadequate; “inadequate” is defined in this context as not consistently actuating in response to changing accelerations and/or frequencies.

A summary of the test results can be seen in Tables 8-10. One overall conclusion that can be drawn from these test results is that the possibility of a household gas shut-off valve exists and can be useful to the homeowner. Another company, Southern California Gas Company (SCGC), has unveiled an automatic gas valve shut-off solution (May and Garcia, 1994). In a recent article in the Los Angeles Times, SCGC states that it possesses a shut-off valve that will trigger at a seismic shock of 5.4 magnitude or greater (Martin, 1996). The triggering mechanism consists of a simple 2.5-inch aluminum cube holding a stainless steel ball that tips off a pedestal and into the gas stream upon shaking from a magnitude 5.4 earthquake or greater. The actual trigger acceleration is unclear. The article then proceeds to state that the valve can be reset by a screwdriver or coin. The valve is sold for $199.00 plus tax and permit.

The Southern California Gas Company valve, while somewhat costly, appears to eliminate the problem of resetting the valve after it has been triggered. After earthquakes, gas companies received thousands of calls of leaks and other gas related problems. It was extremely time consuming for the gas company personnel to answer

all the calls and subsequently residents were forced to manage without gas for long periods of time. The addition of a gas shut-off valve with a reset that the homeowner can utilize may or may not aid the gas companies in their quest to meet the post-event demand for service, since inspection may still be necessary due to the fact that the gas companies are in the best position to determine whether or not there still may be dangerous leaks in the household that have remained undetected by the homeowner.

In summary, the usage of an automatic shut-off valve appears to be theoretically the best way to prevent dangerous gas related fires. The feasibility of its widespread application, however, may still need further research and development. Cost is another factor, which must be considered.

Table 8 - Gas Shut-off Valve Data - Longitudinal Axis (Agbabian Associates, 1995)

Freq. (Hz)	Valve A	Valve B	Valve C	Valve D	Valve E	Valve F	Valve G	Valve H	Valve J	Valve K	Valve L	Valve M	Valve N	Valve O	Valve P
0.5	*	0.075		0.057	0.04	0.07	0.01	0.058	0.07	0.06	0.082	0.082	0.064	0.073	
0.67		0.14	0.09	0.046	0.05	0.09	0.01	0.077	0.1	0.07		0.132	0.096	0.079	0.08
0.83		0.18	0.09	0.046	0.06	0.1	0.02	0.102	0.12	0.1	0.106	0.15	0.103	0.087	0.07
1		0.2	0.1	0.036	0.07	0.09	0.02	0.115	0.14	0.08	0.118	0.16	0.11	0.089	0.06
1.33	0.03	0.21	0.12	0.098	0.09	0.11	0.02	0.114	0.16	0.12	0.139	0.204	0.169	0.108	0.17
1.66	0.25	0.21	0.11	0.045	0.11	0.14	0.02	0.176	0.18	0.16	0.12	0.23	0.187	0.129	0.17
2	0.42	0.25	0.1	0.106	0.14	0.12	0.02	0.249	0.19	0.22	0.094	0.266	0.17	0.112	0.14
2.67	0.67	0.24	0.1	0.083	0.17	0.14	0.04	0.306	0.22	0.26	0.11	0.48	0.16	0.08	0.22
3.33	1.37	0.25	0.09	0.063	0.24	0.17	0.03	0.376	0.21	0.44	0.121	0.26	0.13	0.16	0.33
4	1.22	0.24	0.11	0.085	0.23	0.18	0.03	0.278	0.19	0.44	0.102	0.243	0.11	0.29	0.53
5.33	1.08	0.24	0.13	0.039	0.27	0.29	0.05	0.334	0.31	0.48	0.176	0.266	0.1	0.359	0.52
6.67		0.26	1.2	0.177	0.45	0.29	0.09	0.521	0.33	0.63	0.293	0.214	0.22	0.465	0.56
8		0.32	1.04	0.24	0.45	0.91	0.06	0.52	0.42	0.65	0.126	0.31	0.29	1.7	0.62
10.67		1.15	0.98	0.786	0.69	1.27	0.17	0.63	0.75	0.86	0.952	1.03	0.52	2.56	0.58
13.33		1.45	1.18	2.6	0.81	1.27	0.45	0.81	1.54	1.18	1.29	1.6	0.72	3.26	0.54
15		1.54	1.03	2.36	0.68	1.26	0.34	0.8	1.85	0.91	1.44	2.18	0.8	3.44	0.68

*NOTE: Blank cells indicate either maximum displacement was reached prior to valve actuation, or maximum acceleration (3g) was reached prior to valve actuation.

Table 9 - Gas Shut-off Valve Data - Transverse Axis (Agbabian Associates, 1995)

Freq. (Hz)	Valve A	Valve B	Valve C	Valve D	Valve E	Valve F	Valve G	Valve H	Valve J	Valve K	Valve L	Valve M	Valve N	Valve O	Valve P
0.5	*			0.04	0.05	0.04	0.03	0.03		0.05	0.071			0.051	0.068
0.67		0.12	0.09	0.06	0.08	0.05	0.02	0.04	0.11	0.08	0.099			0.126	0.111
0.83	0.19	0.15	0.1	0.09	0.07	0.09	0.03	0.07	0.13	0.09	0.112	0.16	0.27	0.146	0.114
0.99	0.25	0.17	0.12	0.07	0.09	0.1	0.02	0.08	0.16	0.12	0.135	0.19	0.332	0.156	0.085
1.33	0.27	0.15	0.14	0.14	0.1	0.09	0.03	0.11	0.17	0.12	0.123	0.22	0.380	0.169	0.123
1.66	0.31	0.17	0.11	0.1	0.12	0.13	0.05	0.17	0.18	0.17	0.138	0.25	0.341	0.211	0.263
2	0.24	0.17	0.11	0.11	0.15	0.1	0.05	0.18	0.2	0.23	0.152	0.29	0.258	0.26	0.188
2.66	0.42	0.16	0.11	0.09	0.18	0.11	0.06	0.25	0.21	0.3	0.182	0.28	0.284	0.173	0.302
3.33	0.72	0.14	0.1	0.12	0.18	0.18	0.06	0.22	0.22	0.33	0.135	0.34	0.296	0.091	0.382
4	1.55	0.13	0.11	0.13	0.2	0.2	0.07	0.31	0.21	0.37	0.16	0.28	0.262	0.343	0.801
5.33		0.23	0.14	0.1	0.26	0.28	0.07	0.29	0.2	0.55	0.22	0.34	0.205	0.464	0.581
6.66		0.38		0.18	0.4	0.36	0.11	0.36	0.33	0.54	0.41	0.33	0.589	1.41	0.521
8		0.59		0.22	0.35	0.91	0.16	0.55	0.39	0.55	0.13	0.58	0.589	2.55	0.523
10.67		1.1		0.46	0.69	1.22	0.29	0.63	1.1	0.58	0.66	1.22	0.931	1.98	0.582
13.33		1.73		1.99	0.99	1.08	0.63	0.63	1.18	0.81	1.3	1.81	1.27	6.72	0.636
15		1.83		2.18	1.03	1.49	0.34	0.68	1.6	0.68	1.49	2.52	1.15	7.82	0.69

*NOTE: Blank cells indicate either maximum displacement was reached prior to valve actuation, or maximum acceleration (3g) was reached prior to valve actuation.

Table 10 - Gas Shut-off Valve Data - Vertical Axis (Agbabian Associates, 1995)

Freq. (Hz)	Valve A	Valve B	Valve C	Valve D	Valve E	Valve F	Valve G	Valve H	Valve J	Valve K	Valve L	Valve M	Valve N	Valve O	Valve P
0.5	*	0.9			0.1						0.8				
0.67					0.17						.11				
0.83											.13				
1				.034							.18				
1.33				0.52							0.25	.46	0.504		
1.66		0.8		0.77	0.78				0.62		0.21	.583	0.567		0.62
2		0.82		0.88	0.85			0.9	0.88		0.35	.679	0.662	.783	0.63
2.66		0.86		0.89	1.14			0.64			0.48	.740	0.816	1.27	0.79
3.33		1.01		0.84	1.04			0.69			0.55	.530	1.7	1.03	0.83
4		1.09		1.01	1.15			0.81			0.2	.728	1.1	1.10	1.1
5.33		1.05	1.26	0.99	1.16			1.03			0.58	.581	1.03	.711	1.39
6.66		0.9	1.64	0.99	1.13			1.2	2	1.01	0.41	.884	1.31	.839	1.15
8		1.3	1.5	1.5	1.3			1.14	1.63	1.35	0.58	.948	1.37	1.41	1.3
10.67		0.81	1.5	0.81	0.81			1.1	1.8	1.67	0.46	.698	1.69	1.57	1.51
13.33		0.9	2.54	0.36	0.99			0.72	1.8	1.44	0.63	.908	1.36	1.45	1.45
15		0.8		1.15	0.8			0.68	1.3	1.03	0.57	1.035	1.49	1.84	1.37

*NOTE: Blank cells indicate either maximum displacement was reached prior to valve actuation, or maximum acceleration (3g) was reached prior to valve actuation.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

The basic goal of this research project was to test current fire hazard mitigation systems and proceed to improve upon them where possible. Throughout the experimental phase of the project, observations were made as to the strengths and weaknesses of the restraint methods analyzed and tested. As was stated in Section 1, a restraint method should be durable, cost effective, and easy to install. These three qualities along with the overall objective of fire hazard reduction provided guidelines for evaluation of these restraint methods. The four existing restraint methods displayed different combinations of the aforementioned qualities and it was from these observations that a fifth method, the Bracket method, was conceived. The following paragraphs give a synopsis of the strengths and weaknesses of the five restraint systems.

The Tape method consists of inexpensive materials that can be found in any hardware store. The method was relatively easy to install but there was difficulty found in properly tightening the water heater. This difficulty stems from the nature of he plumbers tape. The tape has alternating 1/8 in. and ¼ in. holes on one-inch centers. This proves to be difficult when trying to line up the larger holes for the lag screws onto a 2x4 stud. The amount of slack in the restraint was over the limit that was acceptable. The Tape method provided average resistance to seismic motion but the resistance was directional. In the forward direction (away from the wall) the plumbers tape was oriented in a way that resisted the motion effectively. But in the backward direction (towards the wall) the straps were at an oblique angle which provided little resistance. Thus, under higher accelerations, the water heater had a tendency to collide with the wall in a violent motion. This lack of bi-directional resistance is due to the negligible compressive strength of the plumbers tape.

The Conduit method portrayed a different set of qualities. The conduit method is inexpensive to purchase and its components can also be bought at any hardware store. Its resistance to seismic motion was very good but the method had one major flaw: it was difficult to install properly. To properly install the conduit method a number of steps were necessary: 1) extra tools including a vise to flatten the ends of the conduit 2) extra material (EMT tubing) is needed because it was next to impossible to cut each piece perfectly the first time and 3) a large amount of time and patience. Once installed the method performed well. The amplification of acceleration, especially at the top of the water heaters, was within reasonable limits and the forces inflicted upon the load cell (gas intake pipe) were the lowest of the four existing methods. The conduit used displayed both compressive and tensile resisting properties because conduit is thin walled galvanized steel tubing. The conduit method can resist motions from any direction, even vertically.

The two manufacturers' methods tested were very similar to each other except that Method A utilized two straps and Method B only one. The costs of installation were not provided by the manufacturers but are presumed to be more expensive than the other methods. Both methods were easy to install and required few tools. These two methods displayed adequate resistance to forward motion but offered no resistance to backward motion. The straps would keep the water heater from overturning but did not aid in the pounding of the heater into the wall. Both of these methods demonstrated the largest displacements, which stems from the one-dimensional strapping technique. Method B was actually more problematic than Method A because only one strap was used for restraint. Very few tests were necessary to evaluate Method B because of its instability. Both methods scored below average in terms of acceleration amplification, displacement and load cell forces generated.

The observations made during the testing phase led to the development of the Bracket method. Through analysis of the strengths and weaknesses of the existing methods, it was conceived that an optimal method could be formulated. This new method should be inexpensive with the necessary materials sold in the average hardware store. The new method should be easy to install and offer resistance in any given direction. The Bracket method demonstrates these properties.

The Bracket method (see Figure 18) follows the same overall installation process with minor differences. A wood ledger is screwed into the wall at the two required heights. This allows for more leeway once the installation actually begins. The Bracket method utilizes the strength of ordinary industrial strength shelving brackets. These brackets are manufactured by many companies and are found in many sizes. The sizes that were researched ranged from 6in x 8in to 24in x 30in. The variety of sizes aids the consumer in searching out the best size that suits him or her. The installation proves to be easier than the other methods because less hole drilling and lining up of studs is involved. The brackets come with pre-drilled holes on both legs and the use of the wood ledger alleviates the problem of lining up holes with stud spacing. The installation was the least tedious of all the methods and the cost of materials was comparable to the lesser expensive OSA methods. Most importantly, the results illustrate the real strength of the Bracket method; resistance to seismic motion. The Bracket method was the stiffest of all the methods tested as demonstrated by the results shown in Table 6. The Bracket method was even tested at higher acceleration levels (near 1.0g horizontal acceleration) than the other restraint methods.

In summary, it is recommended that the Bracket method or other methods displaying similar attributes be used for water heater restraint. The ease of construction, inexpensive cost, and exceptional restraint capabilities are all factors that place the Bracket method over the other restraint systems. The OSA methods are suitable under certain conditions, the conduit method more so than the tape method, but display certain weaknesses in design as mentioned previously. The manufacturers' methods tested are not recommended due to their instability and projected high expense. Gas shut-off valves are also a viable option but the lack of research and high cost are detriments to the average consumer. Shut-off valves have demonstrated potential and

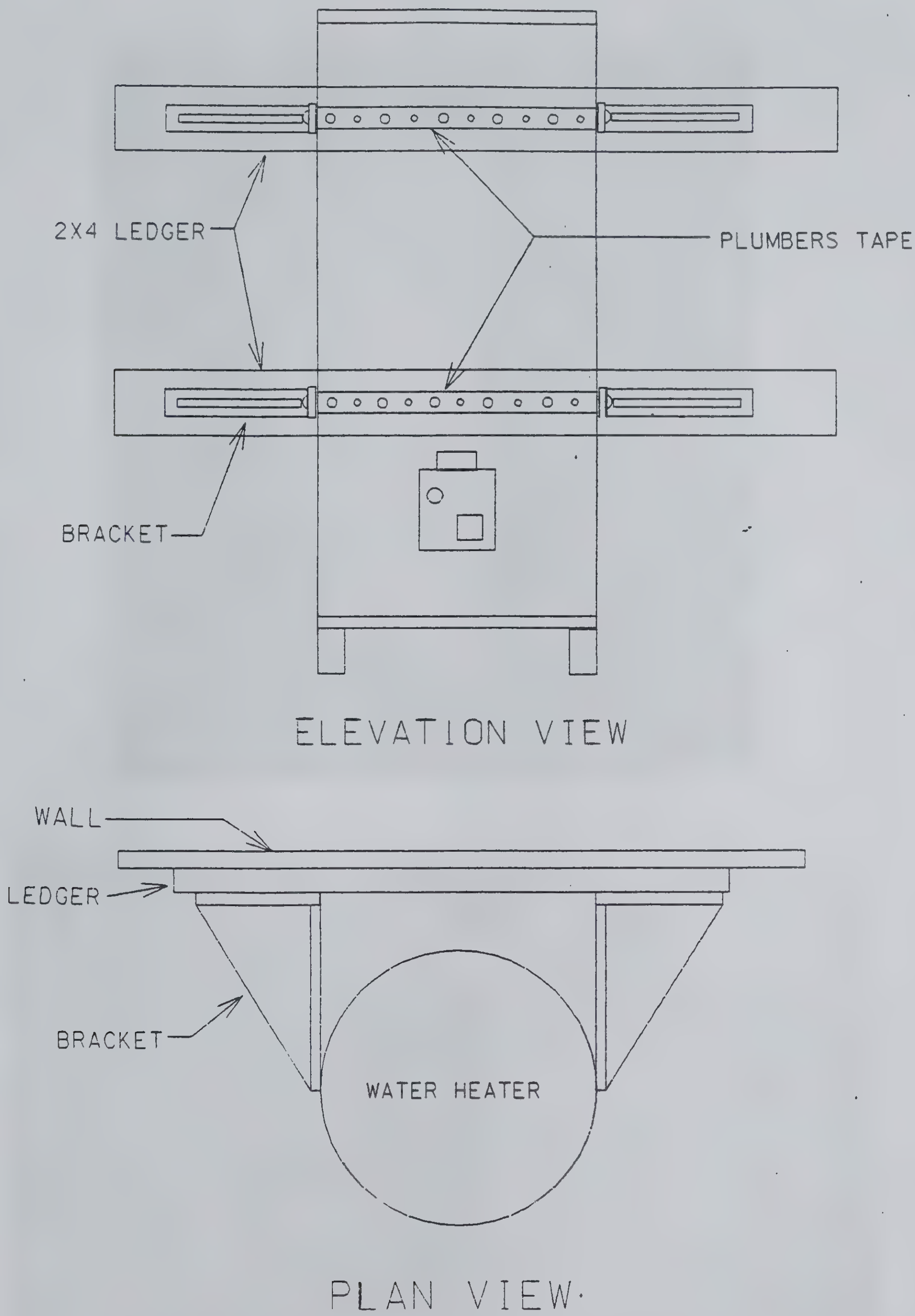
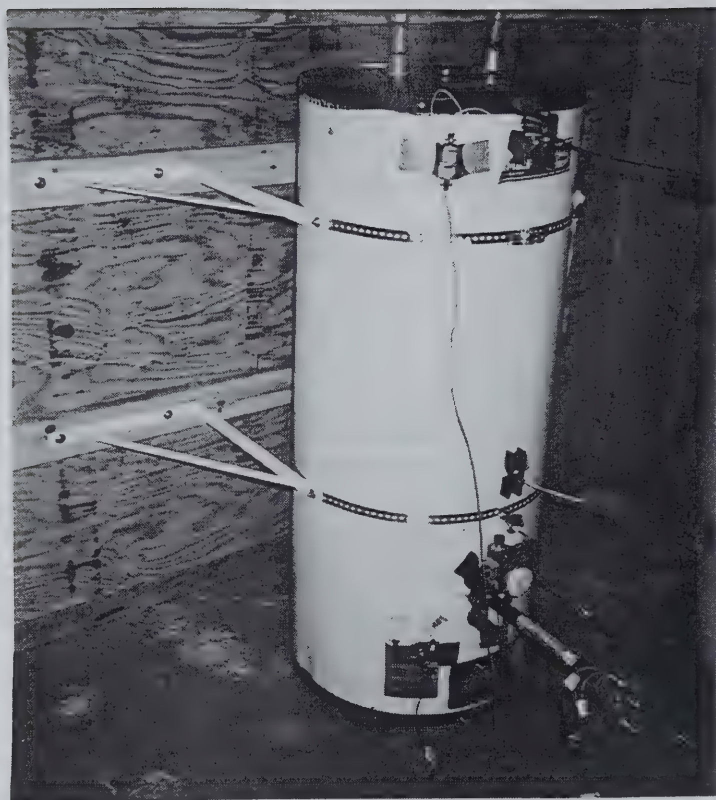


Figure 18 Bracket Method



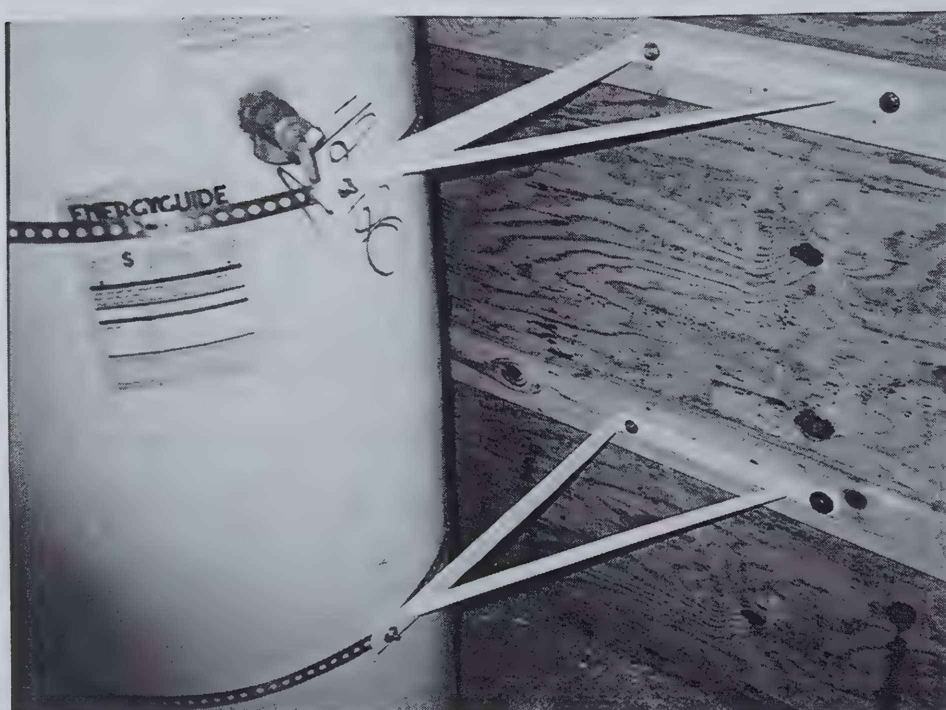


Figure 19 Bracket Method

will no doubt be one of the mitigation methods of choice in the future. However, until further research and development on the serviceability of the valves take place, the recommended system for fire mitigation will be restraint systems such as the Bracket method tested in this work.

SECTION 6

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APPENDIX A

Restraint Method Installation Guides*

* Reproduced from selected pages of California Office of the State Architect (1992).

INSTRUCTIONS FOR INSTALLING A WATER HEATER RESTRAINT FOR CORNER PLACEMENT OF WATER HEATER USING TAPE METHOD

1. Mark water heater 9" down from the top and approximately 4" up from the top of the controls.

2. Using a stud finder or another appropriate method, locate the closest wall stud not directly behind the water heater (see attached detail for illustration). Position of the water tank with respect to the location of the support studs is important. Stretch a string between the support studs and determine if distance to the face of the tank meets the requirements shown in the sketch. If it does not it may be necessary to empty the tank and move it if it has flexible water and gas connections or if not moveable the locations of support can be moved using the detail on page 11.

3. Transfer marks on the water heater horizontally to the adjacent wall where the stud identified in step 2 was located.

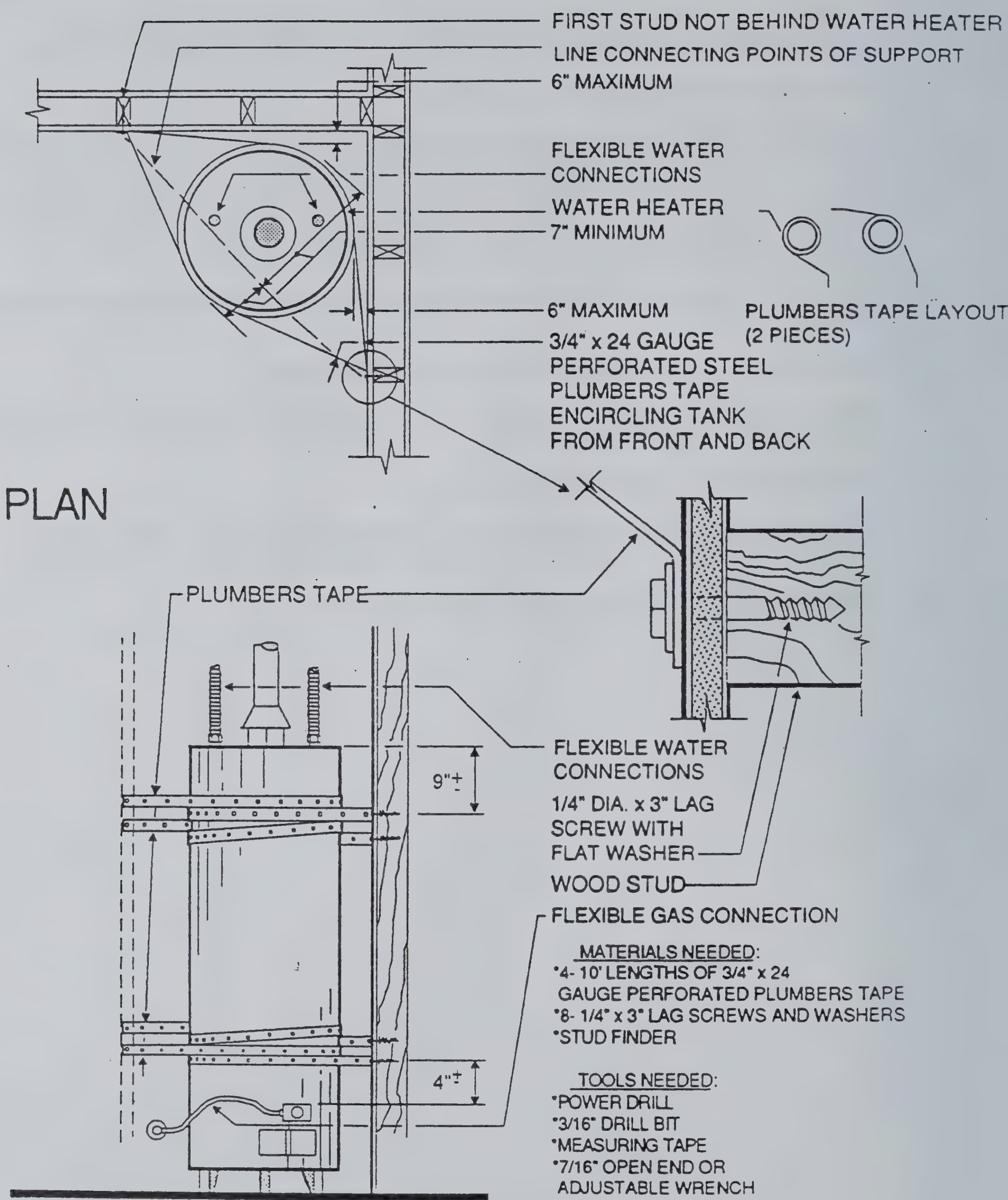
4. Drill a 3/16" diameter pilot hole in the marked studs at least 3" deep.

5. Anchor one end of the tape to the wall with 1/4" diameter lag screw and wrap tape around tank and pull tight to anchor stud on the opposite wall.

6. Mark point for hole in opposite wall and drill pilot hole.

7. Cut off tape and install lag screw with washers. It is important that the tape be tightly stretched. If the tape is not tight, remove the lag screw and place it in the next 1/4" hole in the tape and tighten.

8. Repeat as necessary for all pieces of tape required (See Page 4).



MATERIALS NEEDED:

- 4- 10' LENGTHS OF 3/4" x 24 GAUGE PERFORATED PLUMBERS TAPE
- 8- 1/4" x 3" LAG SCREWS AND WASHERS
- STUD FINDER

TOOLS NEEDED:

- POWER DRILL
- 3/16" DRILL BIT
- MEASURING TAPE
- 7/16" OPEN END OR ADJUSTABLE WRENCH

ELEVATION

WATER HEATER IN CORNER

INSTRUCTIONS FOR INSTALLING A WATER HEATER RESTRAINT FOR STRAIGHT WALL PLACEMENT OF WATER HEATER USING TAPE METHOD

(This method requires that the tank be at least 2 1/2" from the wall. It may be necessary to move the tank to use this method. The water tank can be fairly easily moved if empty and water and gas are connected with flexible connections.)

1. Mark water heater 9" down from the top and approximately 4" up from the top of the controls. Transfer these marks to the wall. (See Page 6).

2. Using a stud finder or another appropriate method, locate the studs to receive the wood 2 x 4 ledger at the heights marked on the wall.

3. Measure the distance between the center line of the studs which are going to support the 2 x 4, add 4", and cut off 2 x 4 to this length.

4. Drill a 1/4" diameter hole in the cut off 2 x 4, 2" in from each end and about the center of 4" dimension. (The 4" dimension is a nominal dimension and is approximately 3 1/2".)

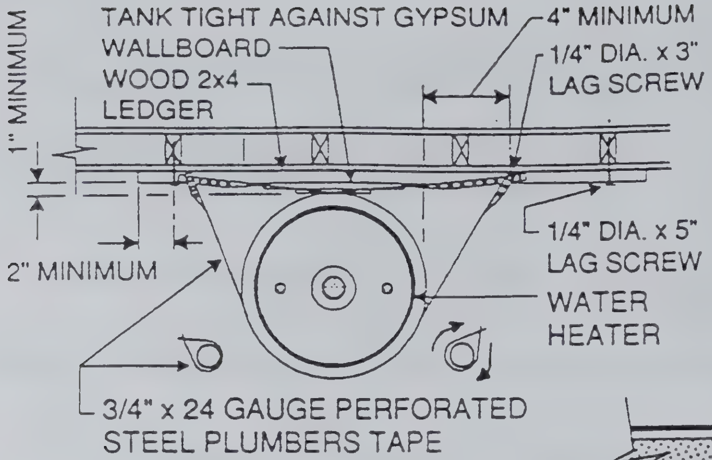
5. Hold the 2 x 4 on the wall at the correct height lining up the 1/4" hole over the center of the wall studs. Through the 1/4" hole, drill a 3/16" diameter hole in the stud as deep as the bit will permit. A 3/16" bit is approximately 3 1/2" long with approximately 1/2" taken up in the part of the drill that holds the bit. Remove the 2x4 from the wall and drill hole to full depth.

6. Place the 2 x 4 on the wall and insert the 1/4" diameter by 5" lag screws through the holes in the 2 x 4 and insert them into the 3/16" holes in the wall. Tighten the screws only enough to hold the 2 x 4 in place as the 2 x 4 will have to be taken down to drill the holes in the top of the 2 x 4 for the connection of the plumbers tape. There is not enough room for the drill when the 2 x 4 is attached to the wall.

7. Mark the appropriate locations for connection of the tape and measure the distance from the face of the 2 x 4 to the face of the tank. Remove the 2 x 4 from the wall. Drill the 3/16" diameter holes in the top of the 2 x 4. On the face of the 2 x 4, where the tank occurs, place the required thickness of gypsum wallboard (drywall)(fireresistant). The tank must fit up against the drywall when the 2 x 4 is in place against the wall. A piece of wood 3 1/2" wide and the thickness needed to obtain the proper fit against the tank may be used next to the 2 x 4. At least 1" thickness of drywall must be installed. The drywall can be attached to the 2 x 4 with nails, but the nails must penetrate the wood by at least 1". The drywall can also be attached by tying it in place with 24 gauge wire.

8. Place 2 x 4 behind the tank and place 1/4" x 5" lag with washer in the ends of the 2 x 4 and tighten. Measure distance from one of the holes in the top of the 2 x 4 around the tank and back to the same hole, then add 2". Cut a length of plumbers tape to this dimension. Place the cut length of plumbers tape and attach to the top of the 2 x 4 with a 1/4" x 3" lag screw with washer through both ends of the tape. Repeat the process for the other hole in the top of the 2 x 4.

9. Repeat the process for the other 2 x 4 and taping. (See Page 6).

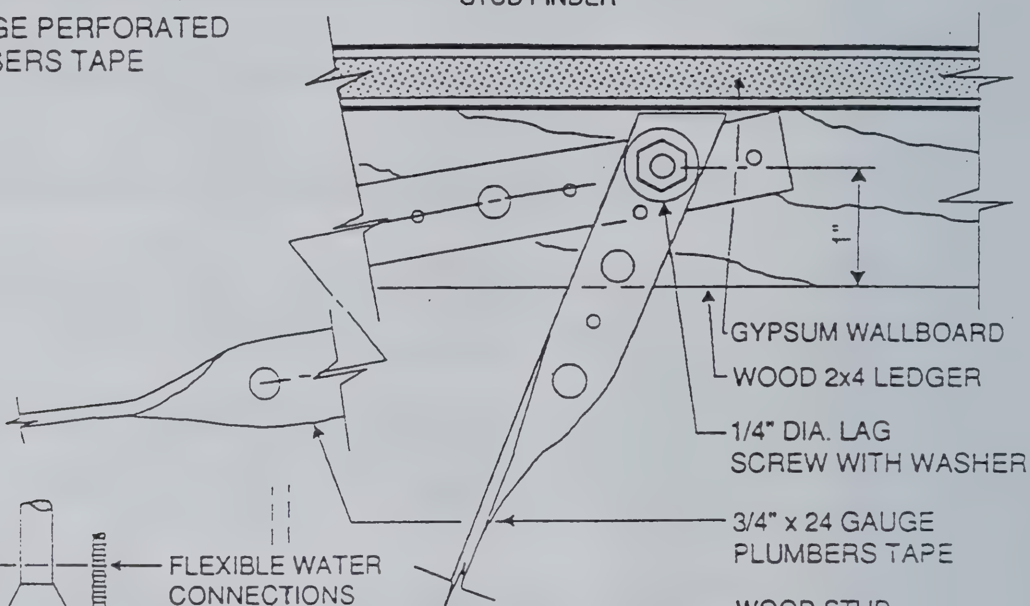


MATERIALS NEEDED:

- GYPSUM WALLBOARD (FIRE RESISTANT DRYWALL)
- 24 GAUGE WIRE
- 2- 2x4 x 4'-0" TO 6'-0" LONG
- 4- 10' LENGTHS 3/4" x 24 GAUGE PERFORATED PLUMBERS TAPE
- 4- 1/4" x 5" LAG SCREWS
- 4- 1/4" x 3" LAG SCREWS

TOOLS NEEDED:

- POWER DRILL
- 1- 1/4" DRILL BIT
- 1- 3/16" DRILL BIT
- STUD FINDER
- MEASURING TAPE
- 7/16" OPEN END OR ADJUSTABLE WRENCH



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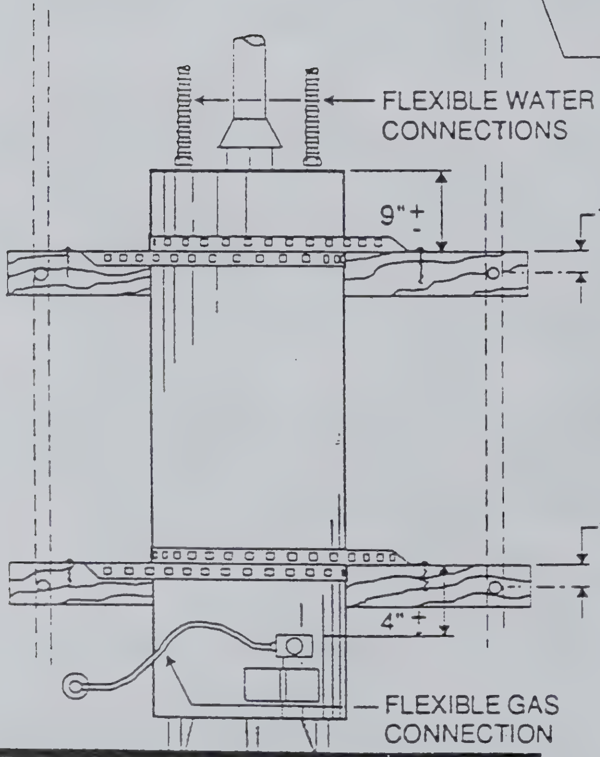
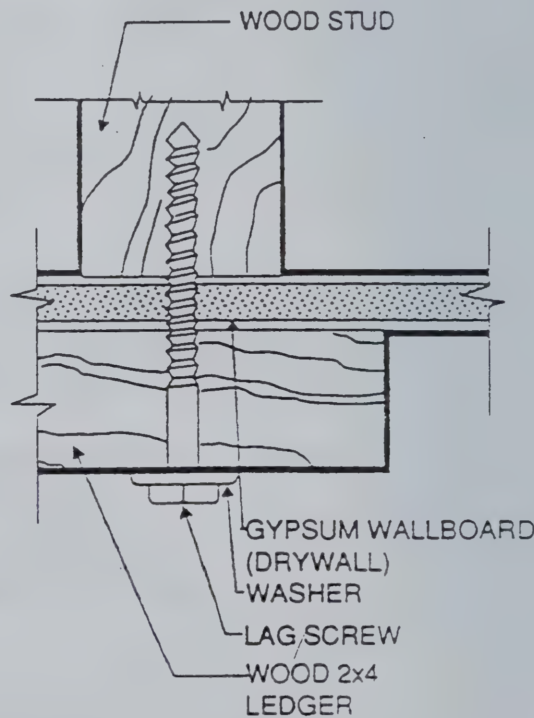




ELEVATION

WATER HEATER ON STRAIGHT WALL

INSTRUCTIONS FOR INSTALLING A WATER HEATER RESTRAINT FOR WATER HEATER ON STRAIGHT WALL USING CONDUIT METHOD

1. Mark water heater 9" from top and approximately 4" up from the top of the controls. Transfer these marks to the wall. Locate wood studs in the wall on both sides of the water heater (See Page 8).

2. Using a stud finder or another appropriate method, locate the closest wall stud not directly behind the water heater (See attached detail for illustration).

3. Transfer marks on the water heater horizontally to the adjacent wall where the stud identified in step 2 was located.

4. Drill a 3/16" diameter, 3" deep pilot hole at the locations for the 1/4" diameter by 3" lag screws.

5. Measure around the water tank and add 2" to the measurement. Cut two pieces of 3/4" x 24 gauge perforated steel plumbers tape to this length. Place a bolt with washer through end hole of one end and bend out 90 degrees as close to the edge of the washer as possible. Most plumbers tape comes with 1/4" diameter holes 1" apart with 1/8" diameter holes in between. The tape can be easily broken at the smaller holes by grabbing the tape with pliers and bending several times.

6. Place tape around tank and place bolt with washer through the nearest hole in the end of the tape, place a washer and nut on the bolt and tighten. The tape should be tight. If the tape is not tight, remove the bolt, place it through the next adjacent 1/4" diameter hole and tighten.

7. Using a measuring tape, measure the distance from the hole in the stud to a point on the tape which is tangent or almost tangent to the tank at one of the holes in the tape. Add 1" to these measurements and cut 1/2" diameter conduit to this length. Repeat this for each piece of conduit.

8. Using a hammer or vice, flatten 1" at each end of the 4 pieces. Be sure to flatten both ends of the conduit in the same plane.

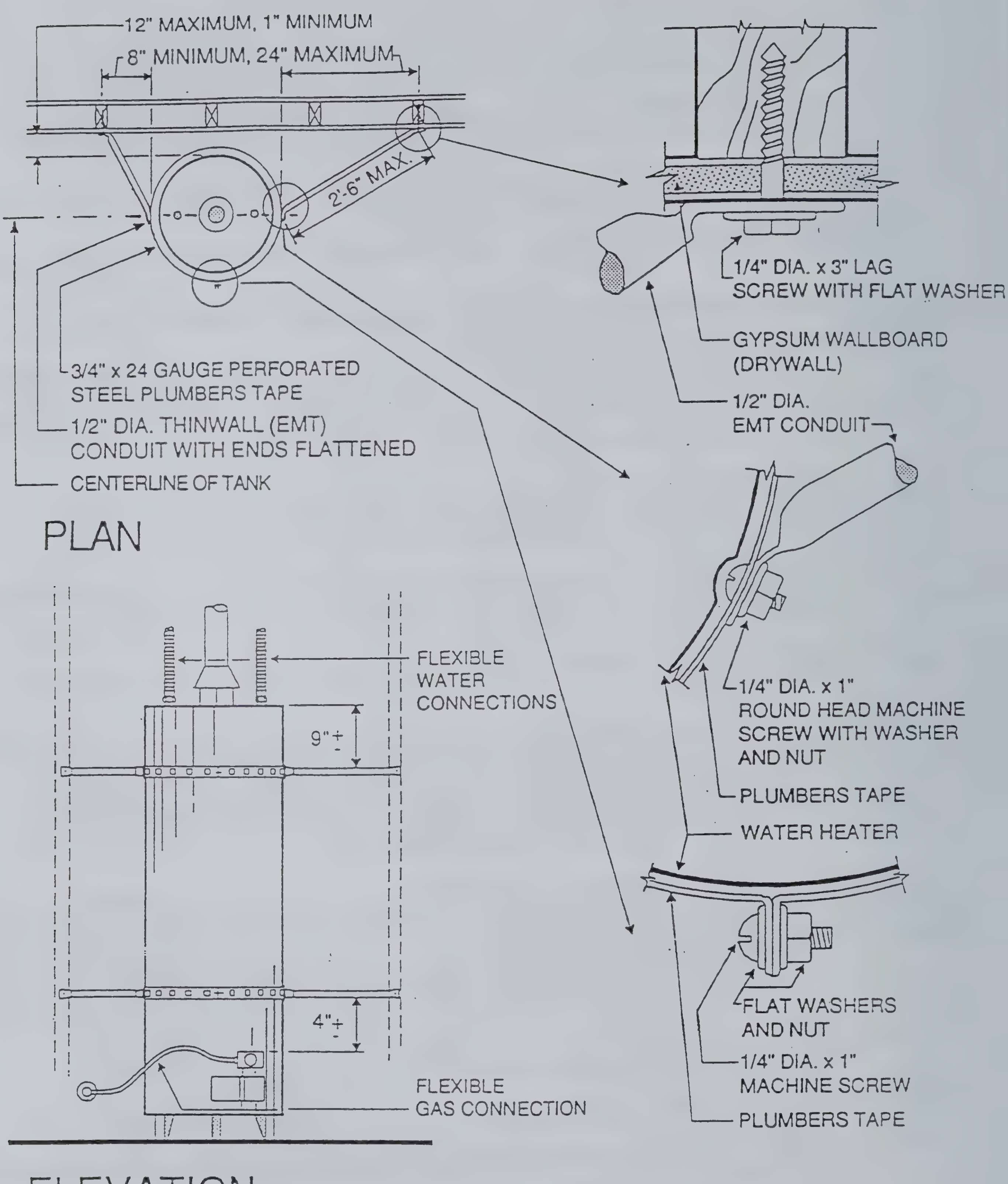
9. Drill a hole in one end of each conduit approximately 1/2" from each end. Measure 1" in from each end and bend up at approximately 45 degrees. This angle will have to be corrected slightly as the work progresses. Hold conduit on the wall with the hole in the conduit over the hole in the wall, and mark the other end at one of the holes in the plumbers tape. Mark holes in the tape and on the tank and conduit. Take down conduit and drill a hole at the mark for the bolt through the flattened end of the conduit. Repeat for the conduit on the other side.

10. Loosen strap around the tank and place a bolt with washer from the inside through the holes in the tape at all locations. Tighten the tape around the tank so that the bolts are at the marks on the tank. It may be easier to do one side of the tank at a time, as positioning of the tape can be difficult. Place conduit on bolt protruding from the strap and place a washer and nut on the bolt and tighten. (A 4d finish nail inserted in the slot in the bolt will prevent the head from turning.) Position the opposite end at the hole in the wall and insert lag screw with washer and tighten. Do not drive lag screw with hammer.

11. Repeat the above procedure for the rest of the conduits. (See Page 8).

12. See Page 11 for alternate where stud locations do not meet limitations shown on Page 8.

NOTE: The 1/4" x 1" bolts referred to above are called 1/4" x 1" round head machine screws with nut at the hardware store.



SEE PAGE 10 FOR MATERIALS AND TOOLS

WATER HEATER ON STRAIGHT WALL

INSTRUCTIONS FOR INSTALLING A WATER HEATER RESTRAINT FOR CORNER PLACEMENT OF WATER HEATER USING CONDUIT METHOD

1. Mark water heater 9" down from top and approximately 4" up from the top of the controls. Transfer these marks to the wall. Locate wood studs in the wall on both sides of the water heater (See Page 10).

2. Using a stud finder or another appropriate method, locate the wall studs that meet the minimum and maximum criteria shown on page 10. (See attached detail for illustration).

3. Transfer marks on the water heater horizontally to the adjacent wall where the stud identified in step 2 was located.

4. Drill a 3/16" diameter, 3" deep pilot hole at the locations for the 1/4" diameter by 3 1/2" lag screws.

5. Measure around the water tank and add 2" to the measurement. Cut two pieces of 3/4" x 24 gauge perforated steel plumbers tape to this length. Place a bolt with washer through end hole of one end and bend out 90 degrees as close to the edge of the washer as possible. Most plumbers tape comes with 1/4" diameter holes 1" apart with 1/8" diameter holes in between. The tape can be easily broken at the smaller holes by grabbing the tape with pliers and bending several times.

6. Place tape around tank and place bolt with washer through the nearest hole in the end of the tape, place a washer and nut on the bolt and tighten. The tape should be tight. If the tape is not tight, remove the bolt, place it through the next adjacent 1/4" diameter hole and tighten.

7. Using a measuring tape, measure the distance from the hole in the stud to a point on the tape which is tangent or almost tangent to the tank at one of the holes in the tape. Add 1" to these measurements and cut 1/2" diameter conduit to this length. Repeat this for each piece of conduit.

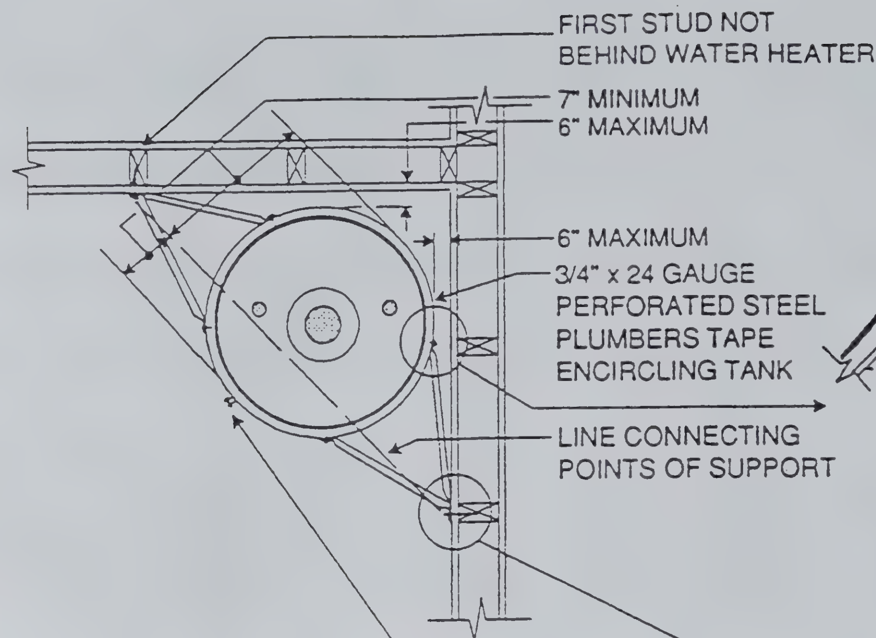
8. Using a hammer or vice, flatten 1" at each end of the 4 pieces. Be sure to flatten both ends of the conduit in the same plane.

9. Drill a hole in one end of each conduit approximately 1/2" from each end. Measure 1" in from each end and bend up at approximately 45 degrees. This angle will have to be corrected slightly as the work progresses. Hold conduit on the wall with the hole in the conduit over the hole in the wall, and mark the other end at one of the holes in the plumbers tape. Mark holes in the tape and on the tank and conduit. Take down conduit and drill a hole at the mark for the bolt through the flattened end of the conduit. Repeat for all other pieces of conduit.

10. Loosen strap around the tank and place a bolt with washer from the inside through the hole in strap at all four locations. Tighten the tape around the tank so that the bolts are at the marks on the tank. It may be easier to do one side of the tank at a time, as positioning of the tape can be difficult. Place conduit on bolt protruding from the strap and place a washer and nut on the bolt and tighten. (A 4d finish nail inserted in the slot in the bolt will prevent the head from turning.) Position the opposite end at the hole in the wall and insert lag screw with washer and tighten. Do not drive lag screw with hammer.

11. Repeat the above procedure for the rest of the conduits. (See Page 10).

NOTE: The 1/4" x 1" bolts referred to above are called 1/4" x 1" round head machine screws with nut at the hardware store.



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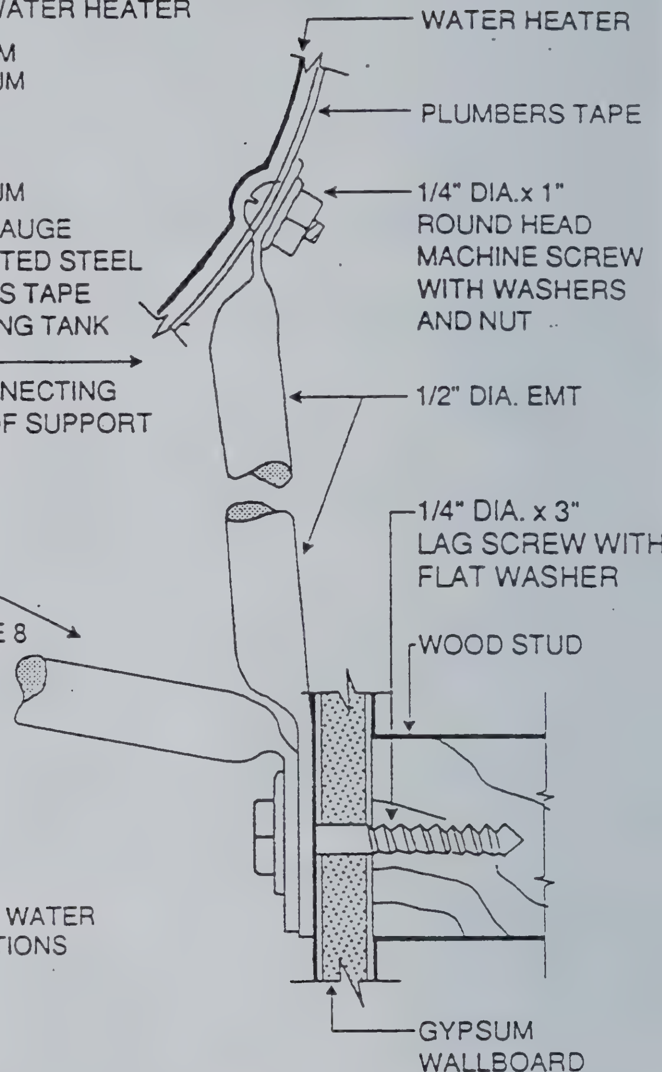
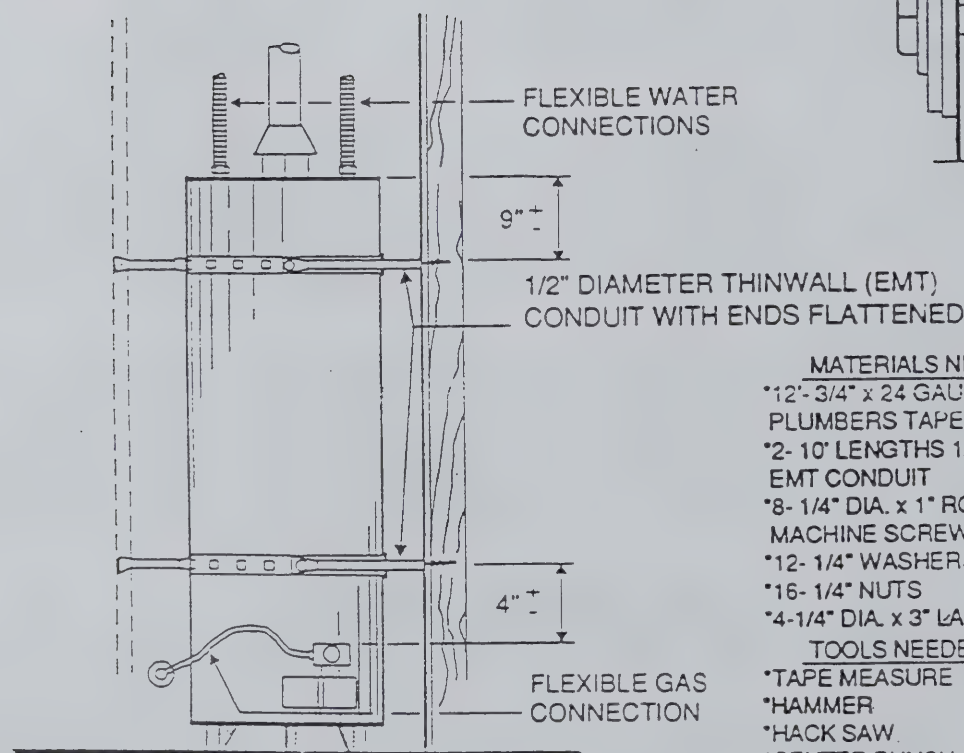




MATERIALS NEEDED:

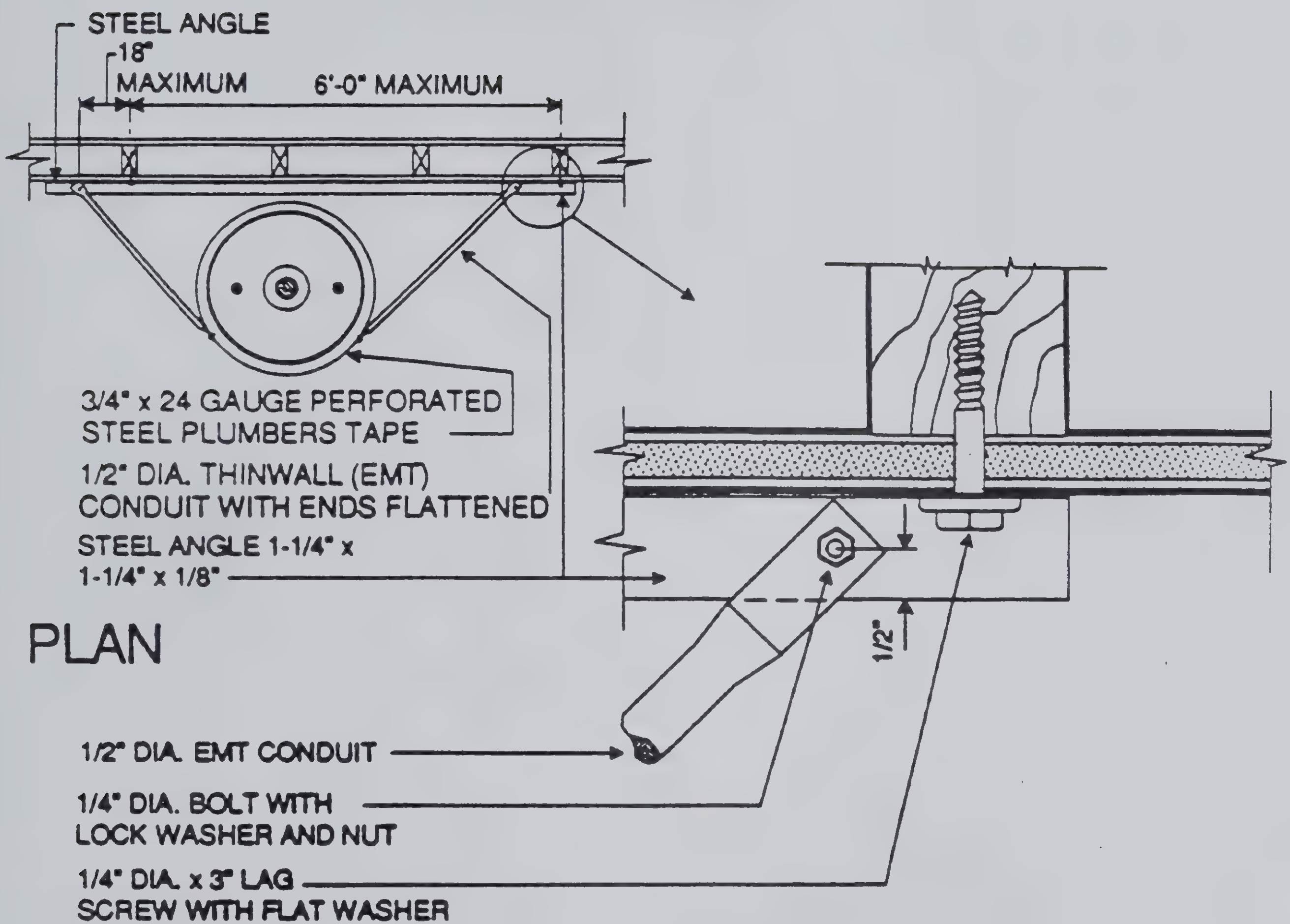
- 12'- 3/4" x 24 GAUGE PERFORATED PLUMBERS TAPE
- 2- 10' LENGTHS 1/2" DIA. EMT CONDUIT
- 8- 1/4" DIA. x 1" ROUND HEAD MACHINE SCREWS
- 12- 1/4" WASHERS
- 16- 1/4" NUTS
- 4-1/4" DIA. x 3" LAG SCREWS

TOOLS NEEDED:

- TAPE MEASURE
- HAMMER
- HACK SAW
- CENTER PUNCH
- STUD FINDER
- POWER DRILL
- 1/4" DIA. DRILL BIT
- 3/16" DIA. DRILL BIT
- 7/16" OPEN END OR ADJUSTABLE WRENCH

ELEVATION

WATER HEATER IN CORNER



ALTERNATE WHERE STUD LOCATIONS DO NOT MEET LIMITATIONS

APPENDIX B

Computer Program " RESTRAINT "

Program Restraint Input Variables

TO	=	Initial Restraint Tension
QO	=	Restraint Material Modulus of Elasticity
CT	=	Restraint Inclination Angle
D	=	Height of Restraint from floor
W	=	Weight of Water Heater Tank
U	=	Coulomb Friction Coefficient
DT	=	Accelerogram time interval
NT	=	Total number of points in accelerogram

PROGRAM RESTRAINT

```
C       This program is used to calculate the sliding motion of water heaters
C       anchored by various restraints at different heights

        Implicit Real*8 (A-H, O-Z)
        Dimension Z(2), R(2), AZ(2), BZ(2), CZ(2), DZ(2)
        Common/P/ TO,QO,H,CT,AXG,AYG,D,W,WM,U,DT

        Open ( unit=1, file='slid.inp', status='old')
        Open ( unit=2, file='sim1h.hst', status='old')
        Open ( unit=3, file='xd_slid.out', status='unknown')
        Open ( unit=4, file='xa_slid.out', status=' unknown')
        Open ( unit=5, file='td_slid.out', status=' unknown')
        Open ( unit=6, file='tt_slid.out', status=' unknown')
        Open ( unit=8, file='max.out', status=' unknown')

        Read(1,*)  TO,QO,CT,D,W,U,DT,NT
        Write(*,*)  TO,QO,CT,D,W,U,DT,NT

        H       = D/TAN(CT)
        WM     =W/9.81
        AXGM=0.0
        XDM   =0.0
        XVM   =0.0
        XAM   =0.0
        TDM   =0.0
        TTM   =0.0

        DO 10 I = 1,2
10      R(I)     = 0.0
        Write (3,100)

        DO  70  M = 1,NT

        Read (2,*)   Time, AXG
        If (AXGM. LE. ABS(AXG))  AXGM = ABS(AXG)
        AXG   = AXG * 9.81

        DO 20 I= 1,2
20      Z(I)  = R(I)

        Call FX  (R,AZ)
        DO 30   I=1,2
30      R(I)   =  Z(I) + 0.5*AZ(I)
```

```
      Call  FX  (R,BZ)
      DO 40   I=1,2
40    R(I)  =  Z(I) + 0.5*BZ(I)

      Call FX  (R,CZ)
      DO 50   I=1,2
50    R(I)  =  Z(I) + 0.5*CZ(I)

      Call FX  (R,DZ)
      DO 60   I=1,2
60    R(I)  =  Z(I) + (AZ(I) + 2*BZ(I) + 2*CZ(I) + DZ(I)) / 6.0

      XD    =R(1)
      XV    =R(2)
      D1    =2.0 * QO * H**2 * R(1)/ (H**2 + D**2)
      D2    =U *(W + 2 *TO * SIN(CT) - WM * AYG)
      IF   (R(2)  .GT.  0.0)  XA = -(D1 + D2) / WM / 9.81
      IF   (R(2)  .LT.  0.0)  XA = -(D1 - D2) / WM / 9.81
      TD    =QO * H * XD/SQRT(H**2 + D**2)
      TT    =TO +TD

      IF  (XDM .LE. ABS(XD))  XDM=ABS(XD)
      IF  (XVM .LE. ABS(XV))  XVM=ABS(XV)
      IF  (XAM .LE. ABS(XA))  XAM=ABS(XA)
      IF  (TDM .LE. ABS(TD))  TDM=ABS(TD)
      IF  (TTM .LE. ABS(TT))  TTM=ABS(TT)
      WRITE(3,200) TIME,XD
      WRITE(4,200) TIME,XA
      WRITE(5,200) TIME,TD
      WRITE(6,200) TIME,TT
70    CONTINUE

      WRITE(8,300)  XDM,XAM,TDM,TTM

100   FORMAT(//4X,'TIME',10X,'XD',11X,'XA',12X,'TD',12X,'TT')
200   FORMAT(F8.3,4E14.6)
300   FORMAT(//30X,'XDM-XAM-TDM-TTM', //5X,  4E14.6)
      STOP
      END


      SUBROUTINE  FX  (R,DX)

      IMPLICIT  REAL*  (A-H, O-Z)
      DIMENSION R(2), DX(2)
```

```
Common/P/ TO,QO,H,CT,AXG,AYG,D,W,WM,U,DT

DX(1)   =DT*R(2)
D1    =2.0 * QO * H**2 * R(1)/ (H**2 + D**2)
D2    =U *(W + 2 *TO * SIN(CT) - WM * AYG)
IF (R(2) .GE. 0.0)  DX(2)  =  -DT * (D1 + D2 +WM*AXG)  / WM
IF (R(2) .LT. 0.0)  DX(2)  =  -DT * (D1 - D2 +WM*AXG)  / WM
RETURN
END
```

APPENDIX C

Physical Test Results

Guide for Reading Sample Output

R1	Tape Method, Corner Placement, Half Full Tank
R3	Method B, Straight Wall Placement, Half Full Tank
R4	Method A, Straight Wall Placement, Half Full Tank
R5	Conduit Method, Corner Placement, Half Full Tank
	Conduit Method, Corner Placement, Full Tank
R6	Tape Method, Straight Wall Placement, Full Tank
R7	Method A, Straight Wall Placement, Full Tank
R8	Conduit Method, Straight Wall Placement, Full Tank
R9	Tape Method, Straight Wall Placement, Full Tank
R10	Tape Method, Straight Wall Placement, Half Full Tank
R11	Conduit Method, Straight Wall Placement, Half Full Tank
R12	Conduit Method, Straight Wall Placement, Empty Tank
R13	Tape Method, Straight Wall Placement, Empty Tank
R14	Bracket Method, Straight Wall Placement, Full Tank

TA = Taft Earthquake
EL = El Centro Earthquake

10 = 100%
15 = 150%
20 = 200%
30 = 300%

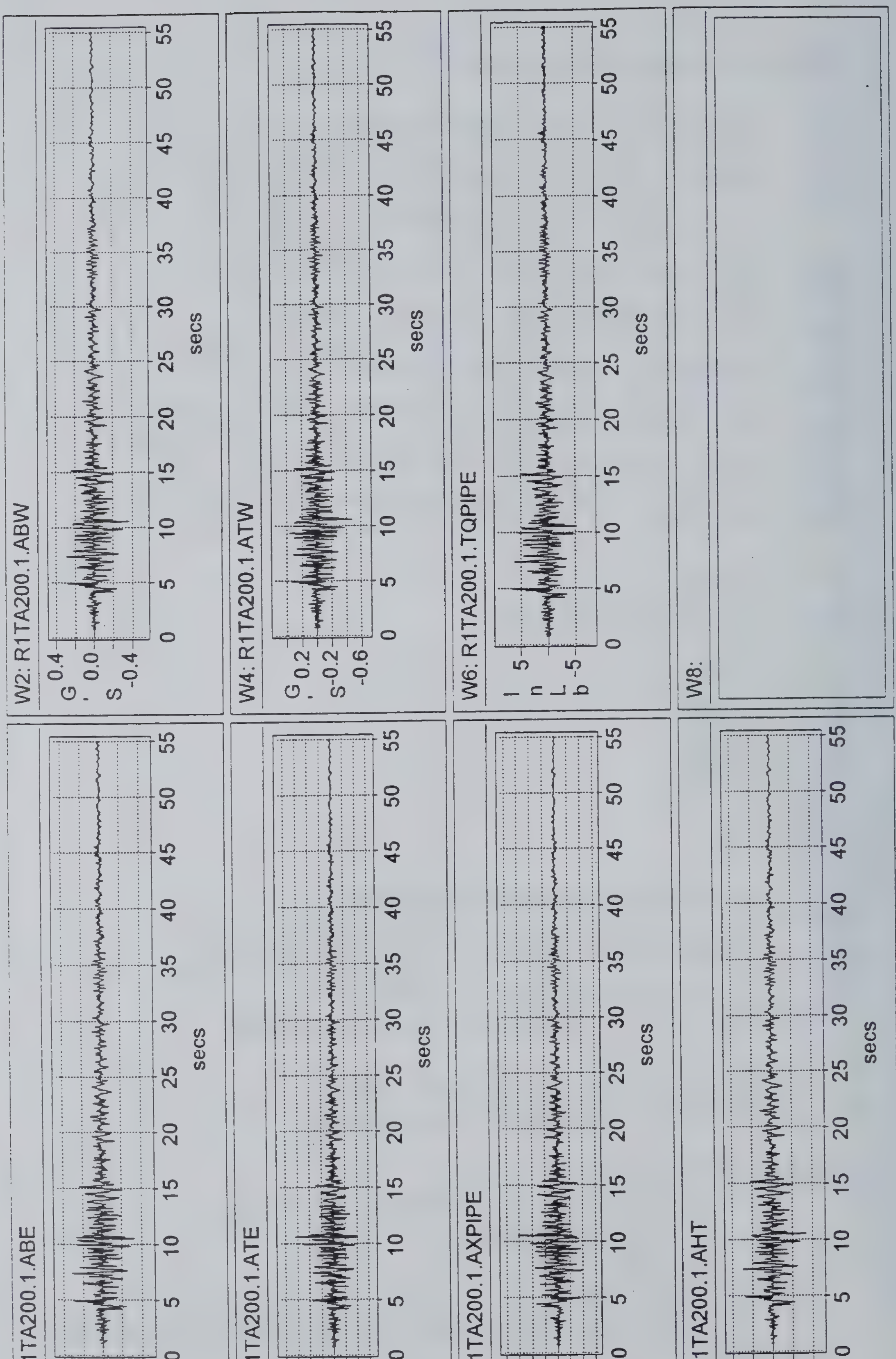
F = Full

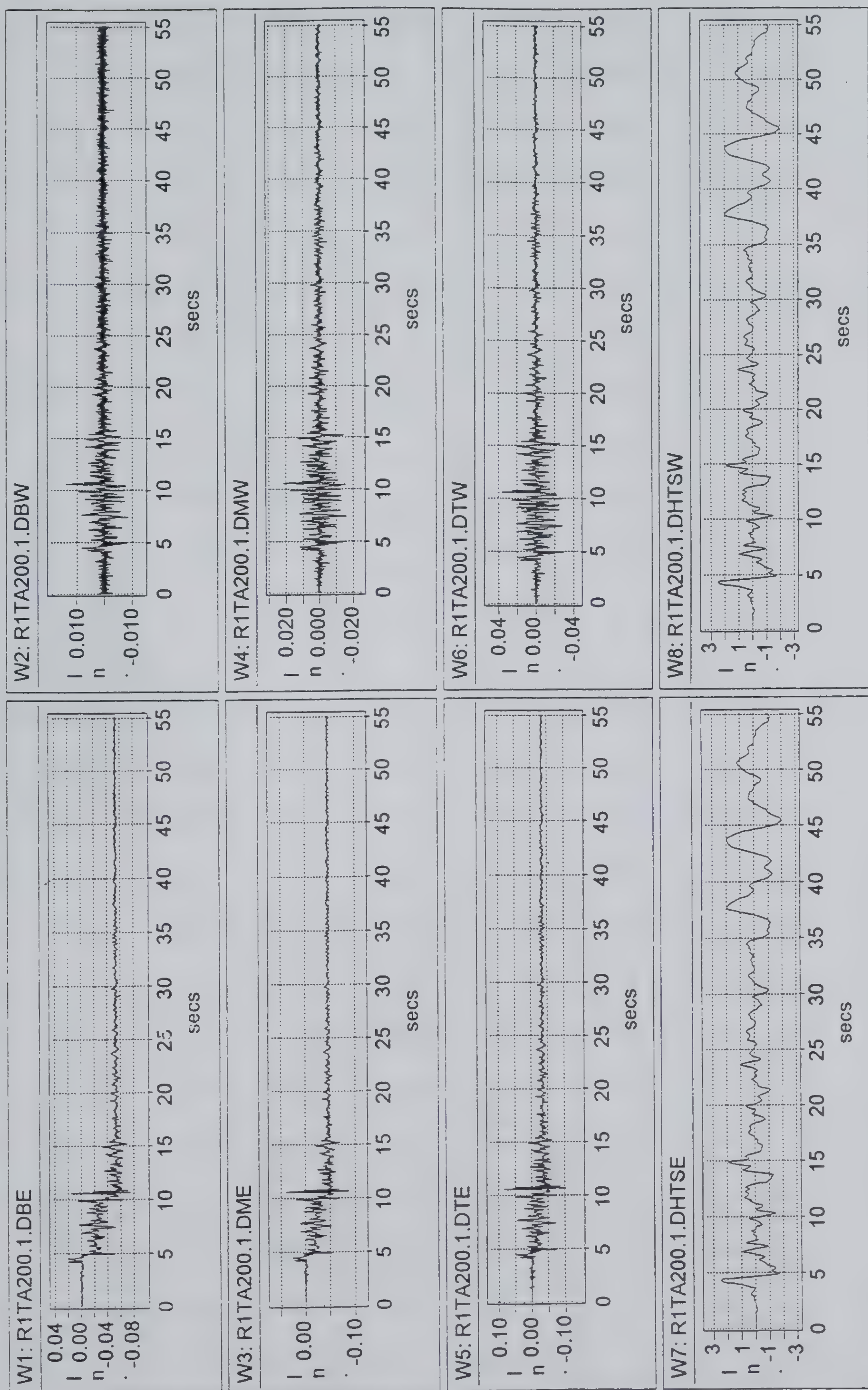
AT = Accelerometer located at top of tank
DB = Displacement Transducer located at bottom of tank
DM = Displacement Transducer located at middle of tank
AB = Accelerometer located at bottom of tank
DT = Displacement Transducer located at top of tank

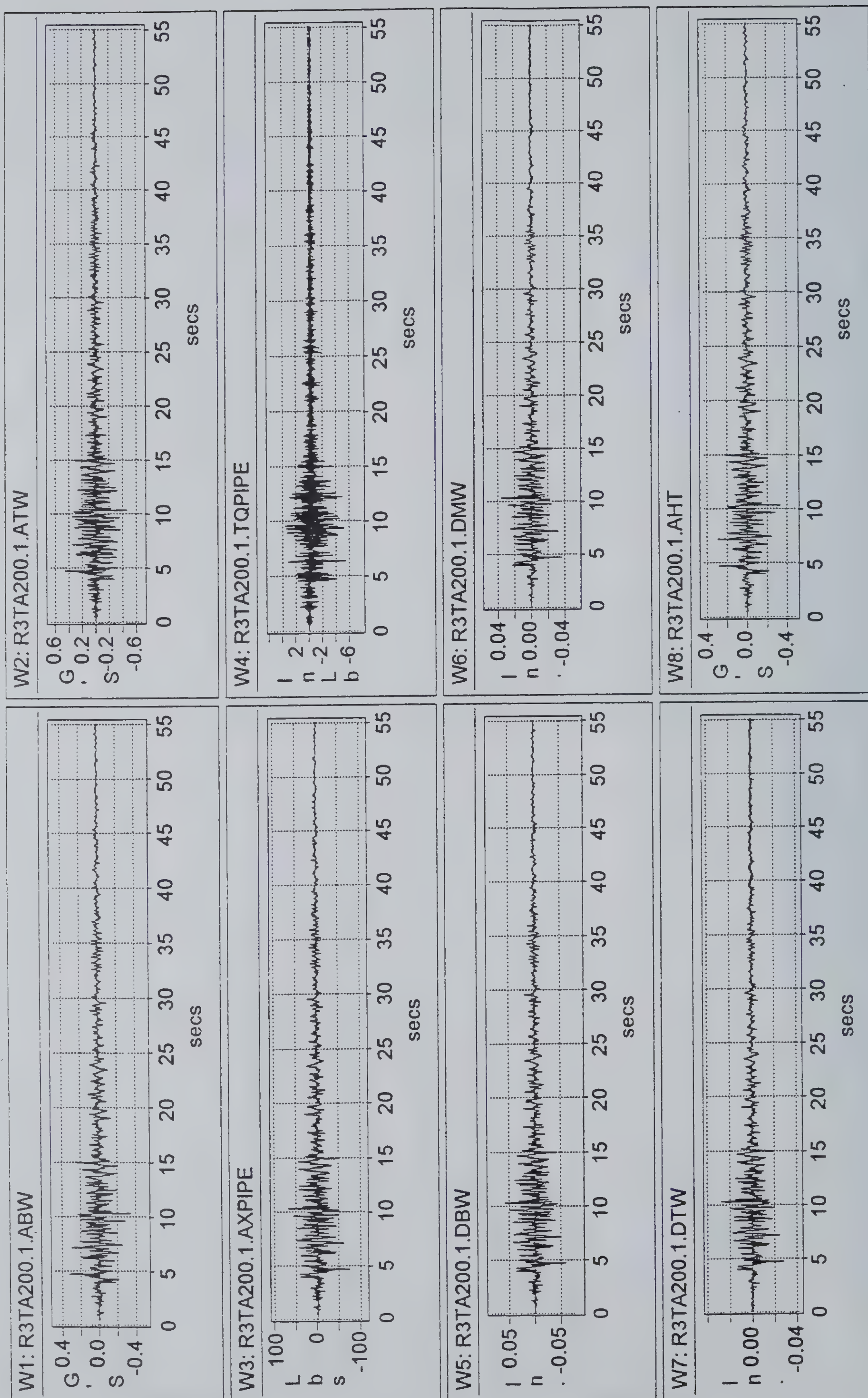
E = East side (used only for double testing)
W = West side (used only for double testing)

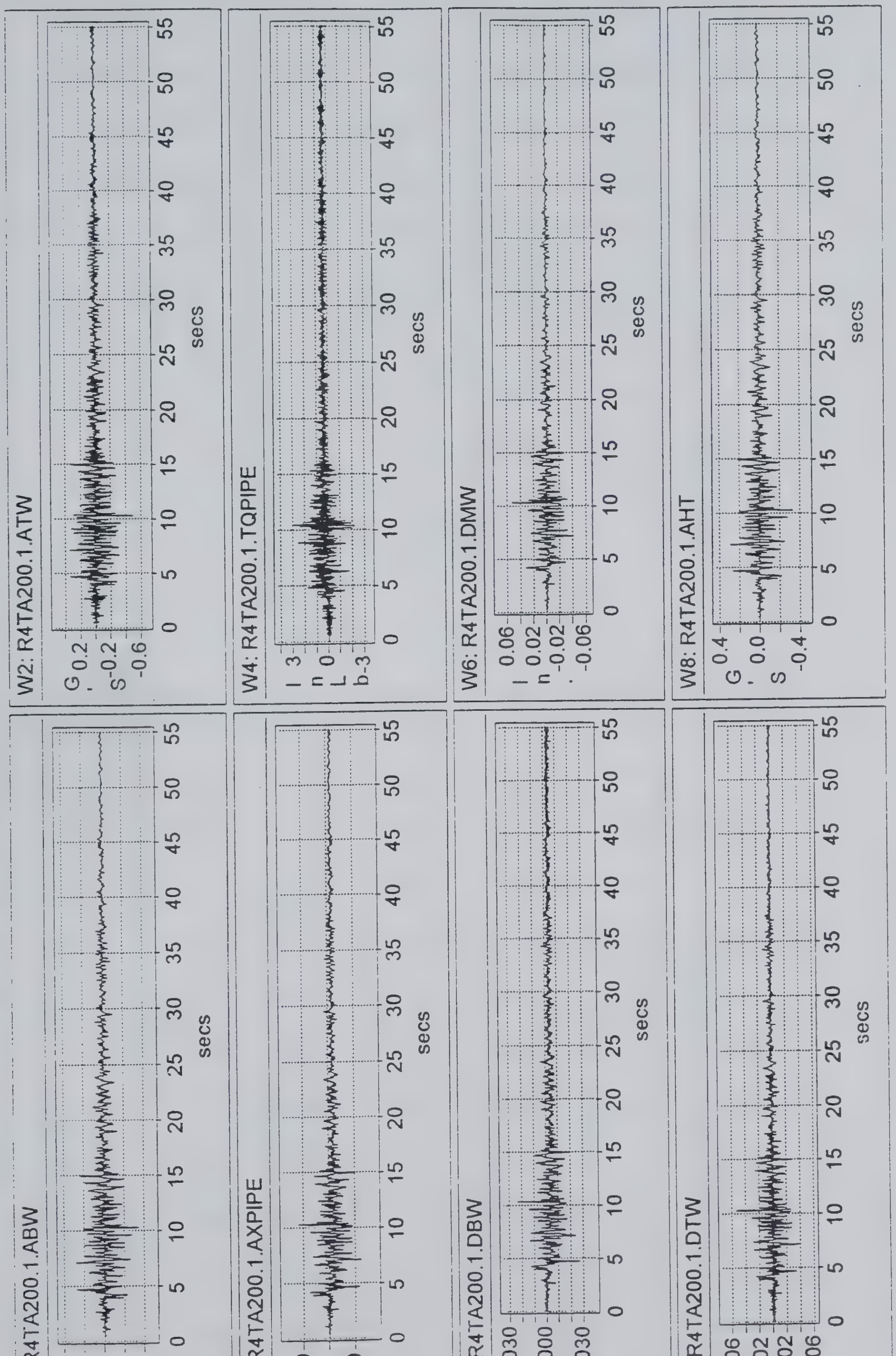
Example : R6TA30F.ATE

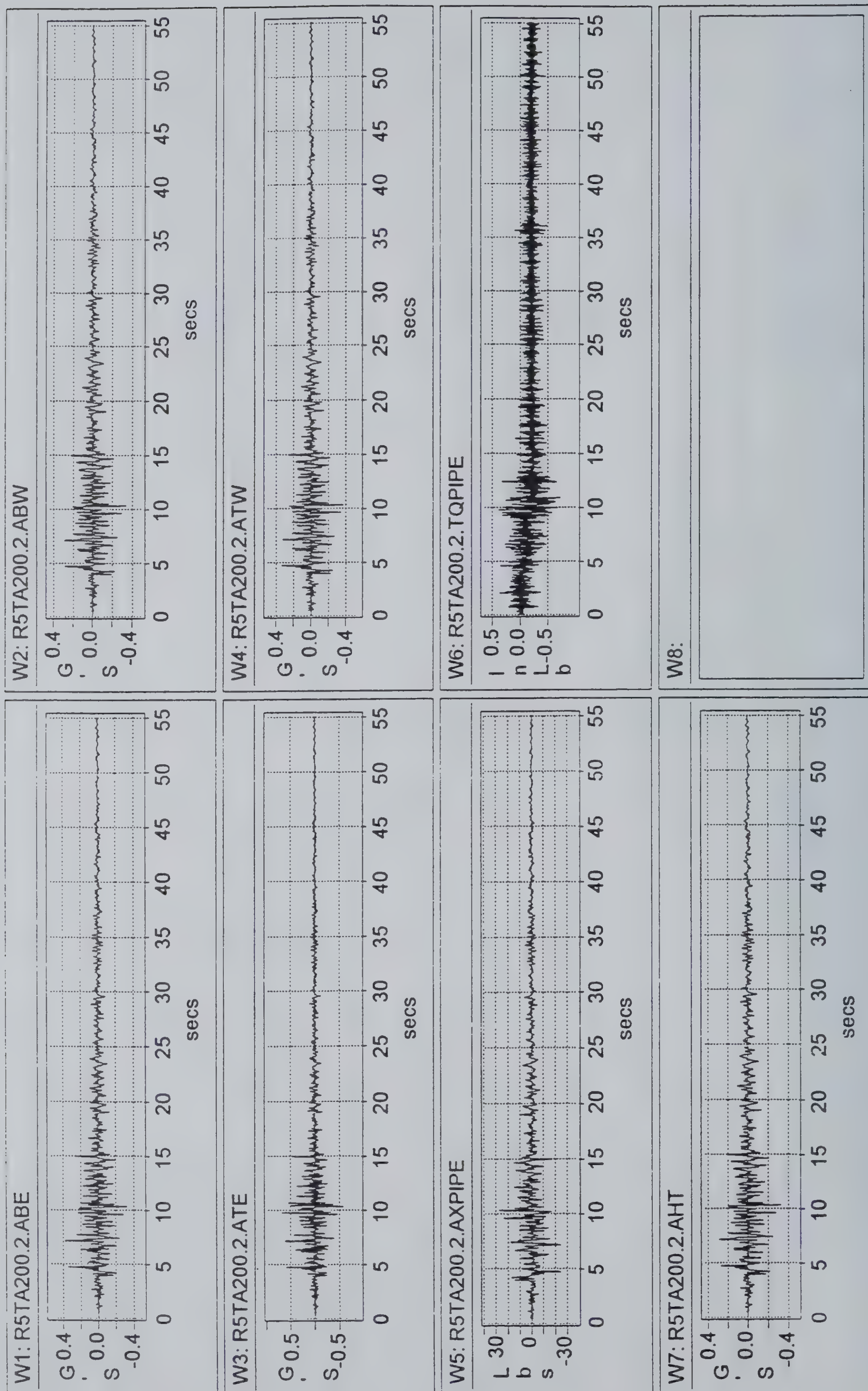
R6 = Tape Method, Straight Wall, Full Tank
TA = Taft Earthquake
30 = 300% level
F = Full Tank
ATE = accelerometer located at top of tank, east designation

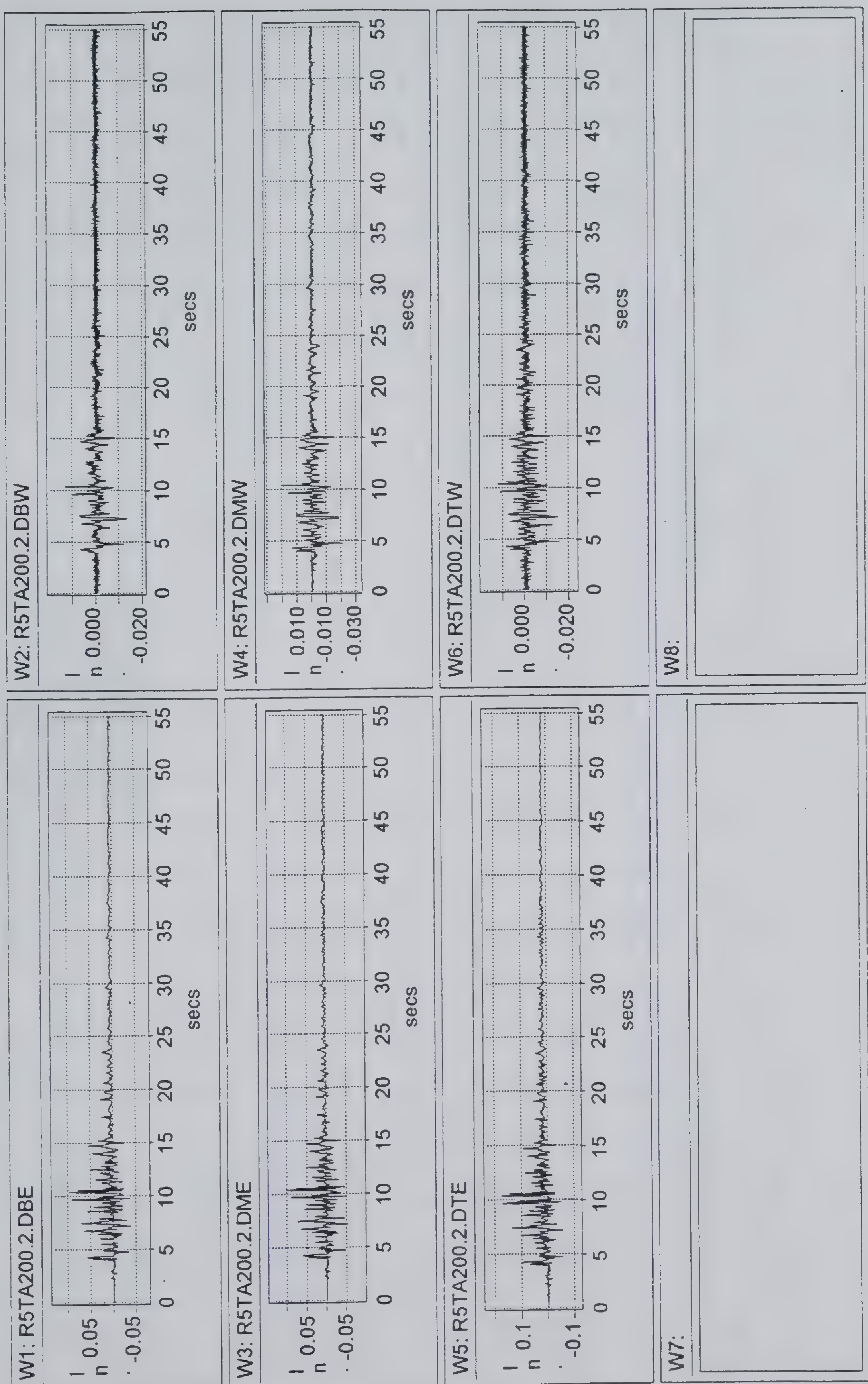

W1: R1TA200.1.ABE
W2: R1TA200.1.ABW
W3: R1TA200.1.ATE
W4: R1TA200.1.ATW
W5: R1TA200.1.AXPIPE
W6: R1TA200.1.TQPIPE
W7: R1TA200.1.AHT
W8:
secs

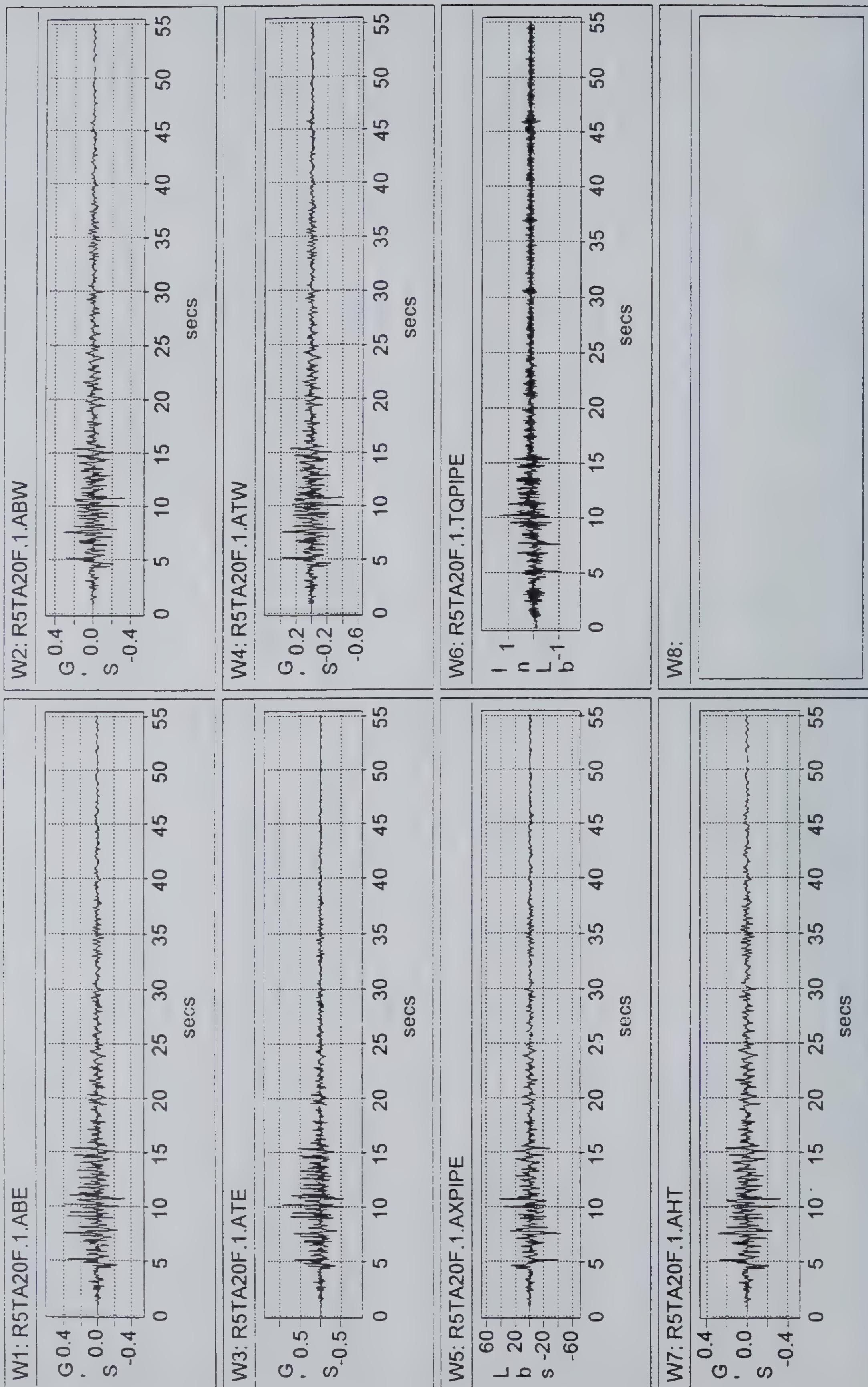

W1: R1TA200.1.DBE
W2: R1TA200.1.DBW
W3: R1TA200.1.DME
W4: R1TA200.1.DMW
W5: R1TA200.1.DTE
W6: R1TA200.1.DTW
W7: R1TA200.1.DHTSE
W8: R1TA200.1.DHTSW
secs
0 5 10 15 20 25 30 35 40 45 50 55

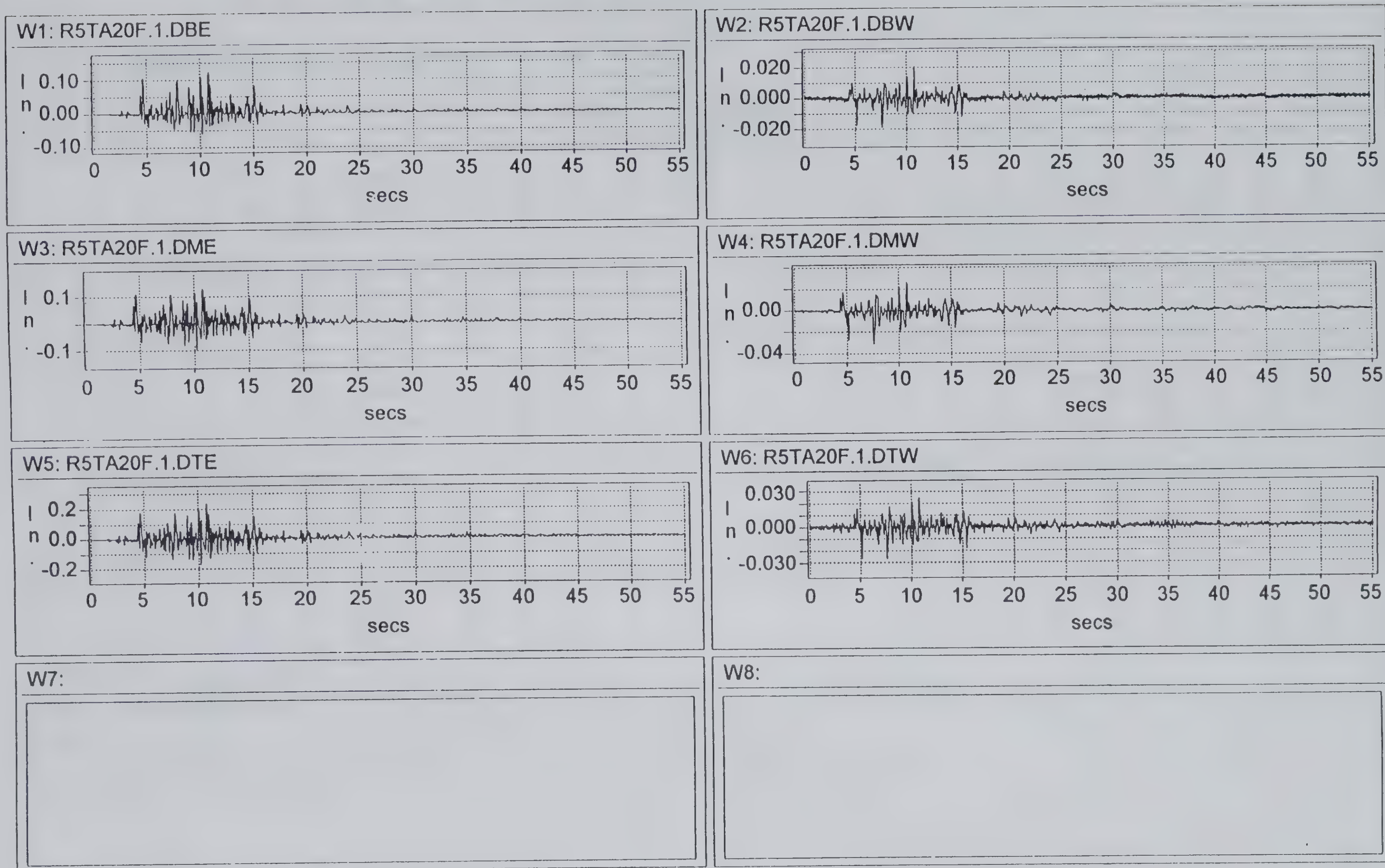

W1: R3TA200.1.ABW
W2: R3TA200.1.ATW
W3: R3TA200.1.AXPIPE
W4: R3TA200.1.TQPIPE
W5: R3TA200.1.DBW
W6: R3TA200.1.DMW
W7: R3TA200.1.DTW
W8: R3TA200.1.AHT
secs


W1: R4TA200.1.ABW
W2: R4TA200.1.ATW
W3: R4TA200.1.AXPIPE
W4: R4TA200.1.TQPIPE
W5: R4TA200.1.DBW
W6: R4TA200.1.DMW
W7: R4TA200.1.DTW
W8: R4TA200.1.AHT
secs

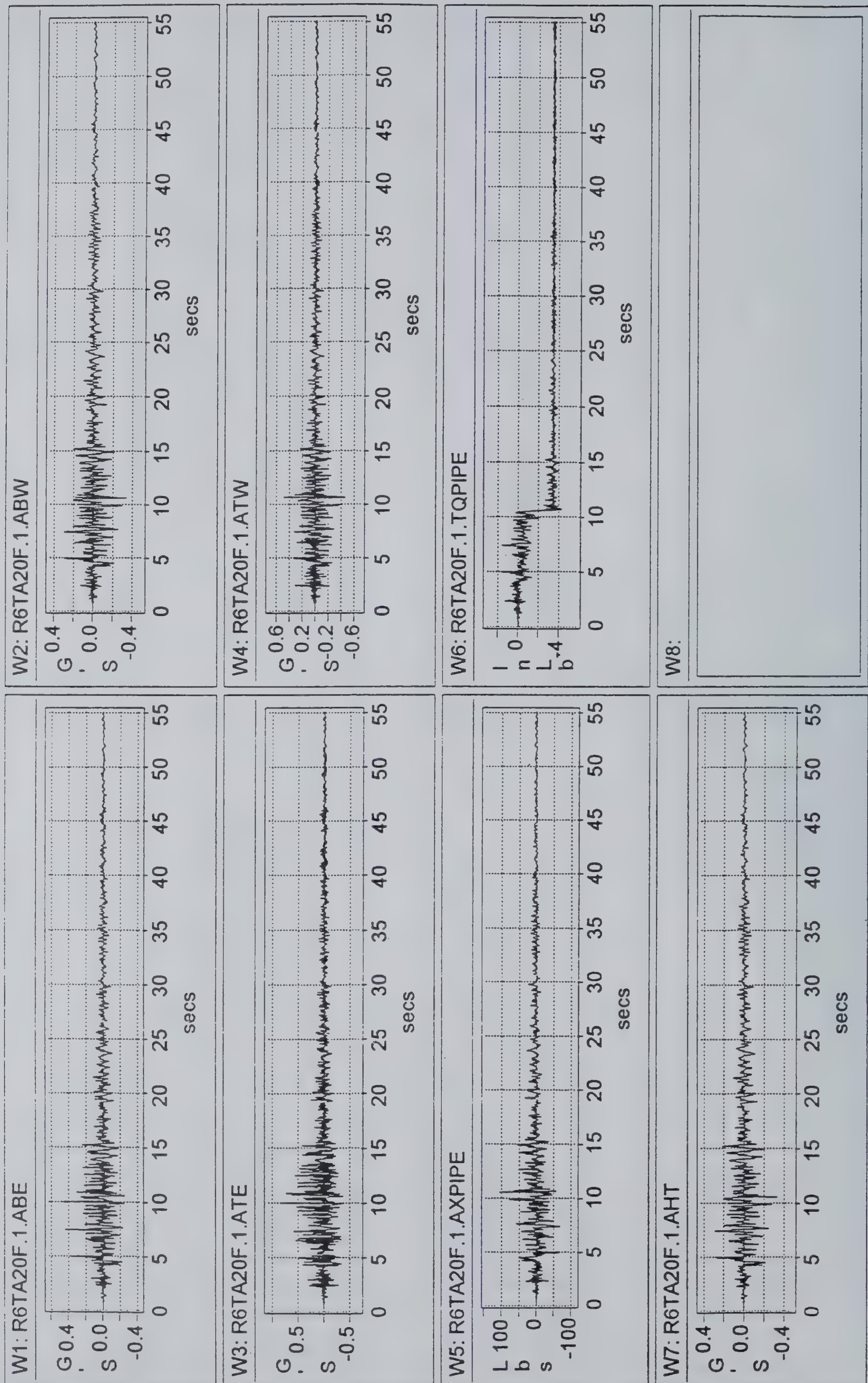

W1: R5TA200.2.ABE
W2: R5TA200.2.ABW
W3: R5TA200.2.ATE
W4: R5TA200.2.ATW
W5: R5TA200.2.AXPIPE
W6: R5TA200.2.TQPIPE
W7: R5TA200.2.AHT
W8:
secs

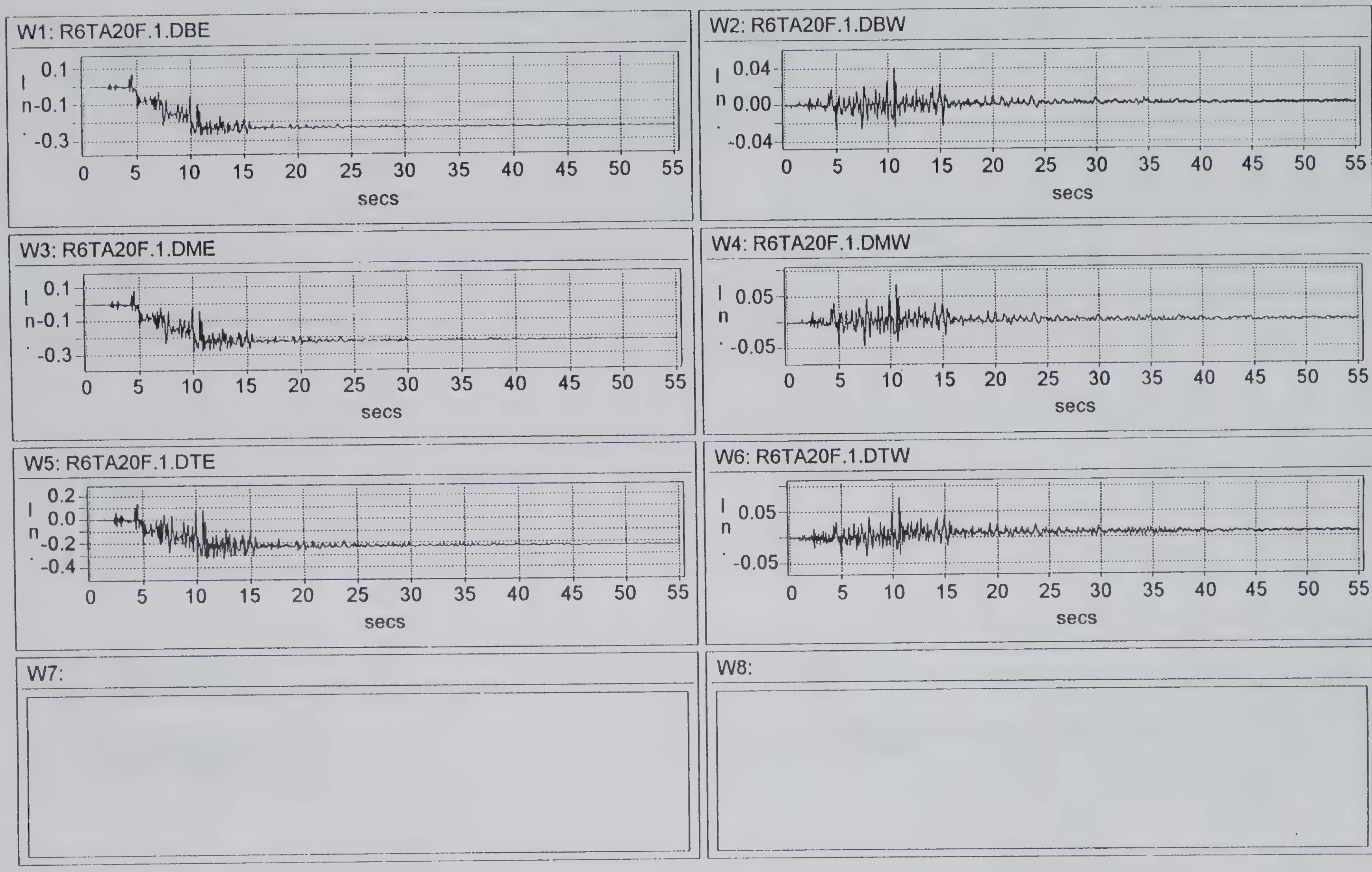

W1: R5TA200.2.DBE
W2: R5TA200.2.DBW
W3: R5TA200.2.DME
W4: R5TA200.2.DMW
W5: R5TA200.2.DTE
W6: R5TA200.2.DTW
W7:
W8:
secs

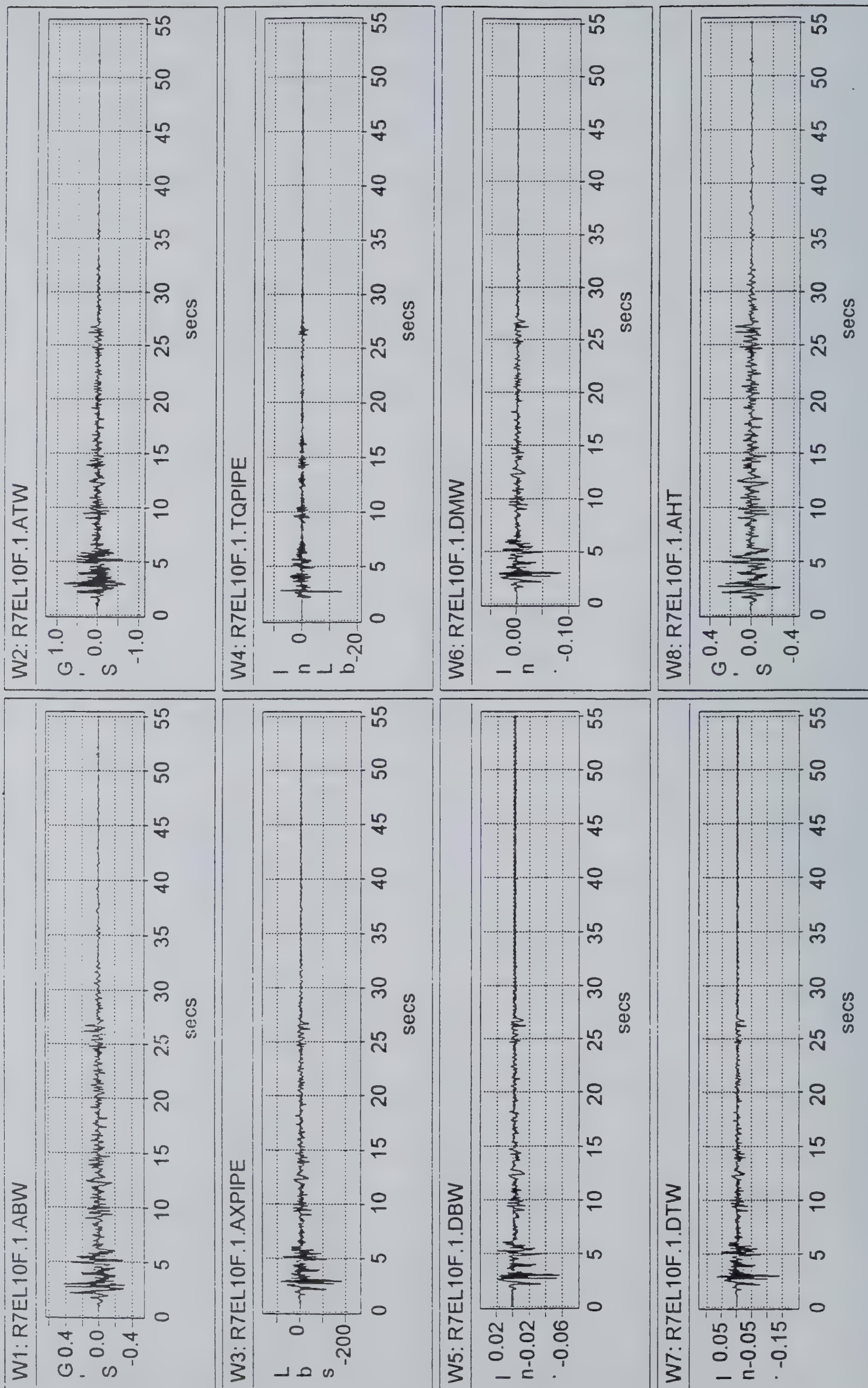

W1: R5TA20F.1.ABE
W2: R5TA20F.1.ABW
W3: R5TA20F.1.ATE
W4: R5TA20F.1.ATW
W5: R5TA20F.1.AXPIPE
W6: R5TA20F.1.TQPIPE
W7: R5TA20F.1.AHT
W8:
secs

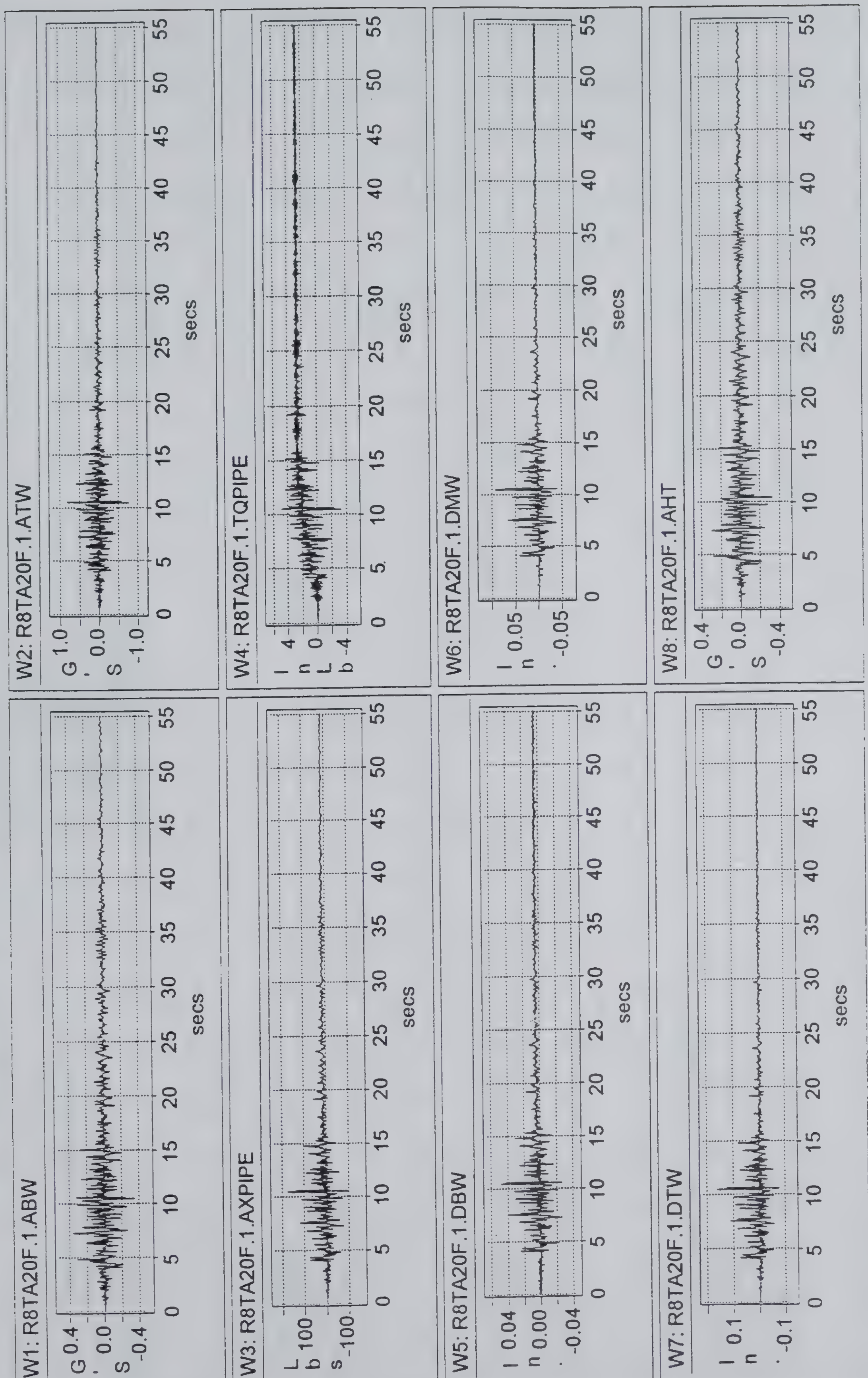


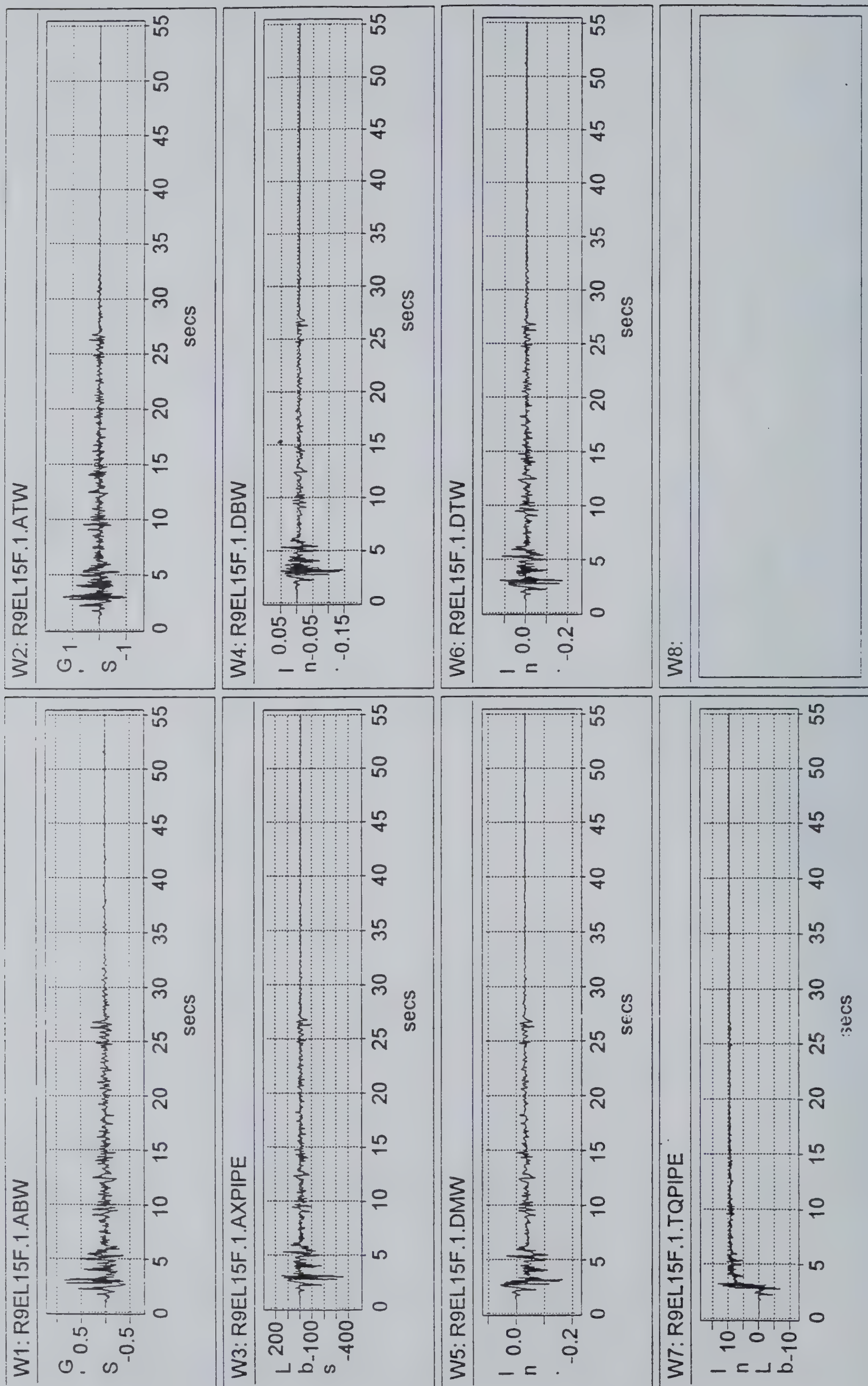
W1: R5TA20F.1.DBE
I n .
0.10
0.00
-0.10
0 5 10 15 20 25 30 35 40 45 50 55
secs
W2: R5TA20F.1.DBW
I n .
0.020
0.000
-0.020
0 5 10 15 20 25 30 35 40 45 50 55
secs
W3: R5TA20F.1.DME
I n .
0.1
-0.1
0 5 10 15 20 25 30 35 40 45 50 55
secs
W4: R5TA20F.1.DMW
I n .
0.00
-0.04
0 5 10 15 20 25 30 35 40 45 50 55
secs
W5: R5TA20F.1.DTE
I n .
0.2
0.0
-0.2
0 5 10 15 20 25 30 35 40 45 50 55
secs
W6: R5TA20F.1.DTW
I n .
0.030
0.000
-0.030
0 5 10 15 20 25 30 35 40 45 50 55
secs
W7:
W8:

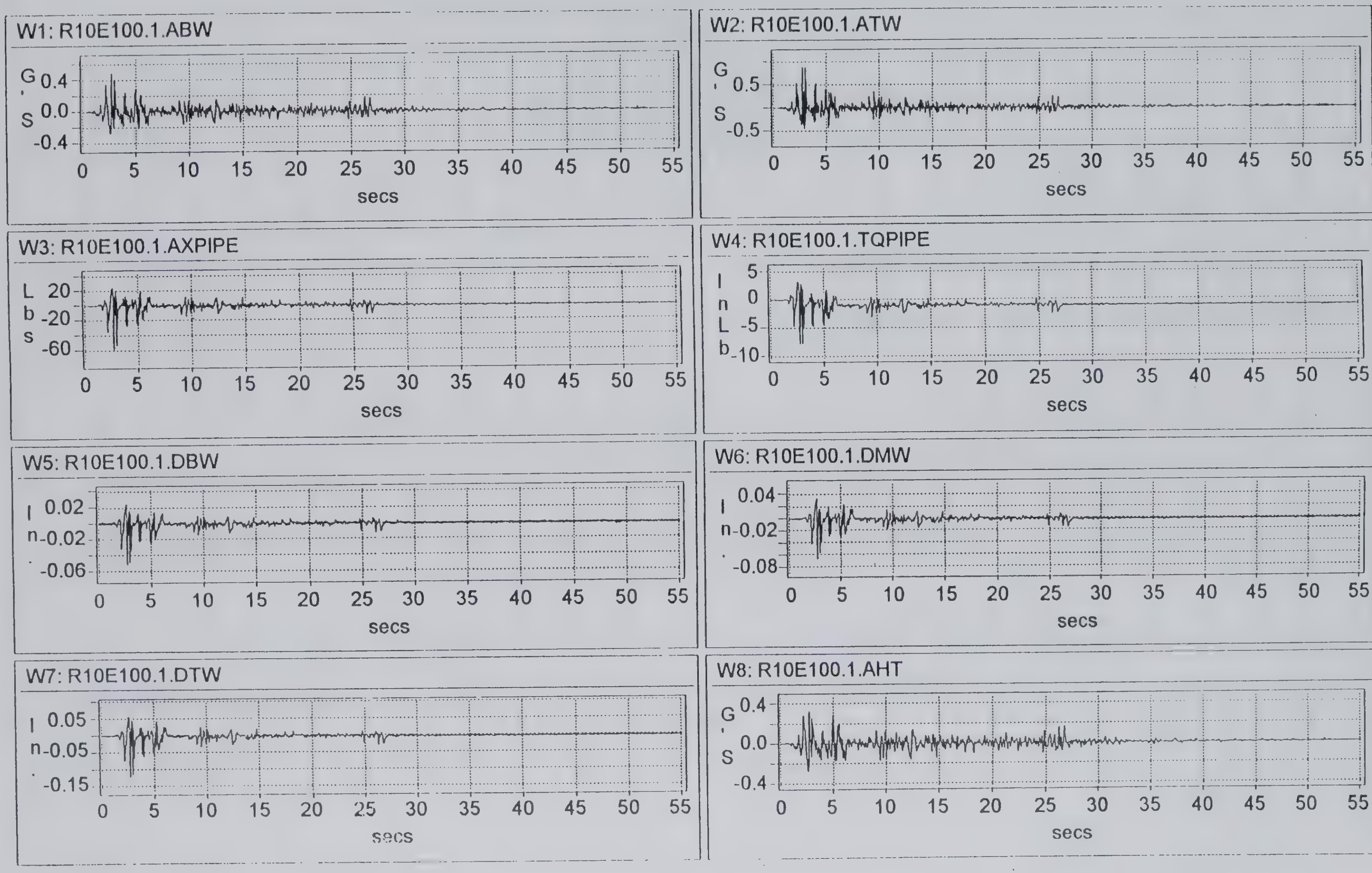

W1: R6TA20F.1.ABE
W2: R6TA20F.1.ABW
W3: R6TA20F.1.ATE
W4: R6TA20F.1.ATW
W5: R6TA20F.1.AXPIPE
W6: R6TA20F.1.TQPIPE
W7: R6TA20F.1.AHT
W8:
secs


W1: R6TA20F.1.DBE
W2: R6TA20F.1.DBW
W3: R6TA20F.1.DME
W4: R6TA20F.1.DMW
W5: R6TA20F.1.DTE
W6: R6TA20F.1.DTW
W7:
W8:
secs

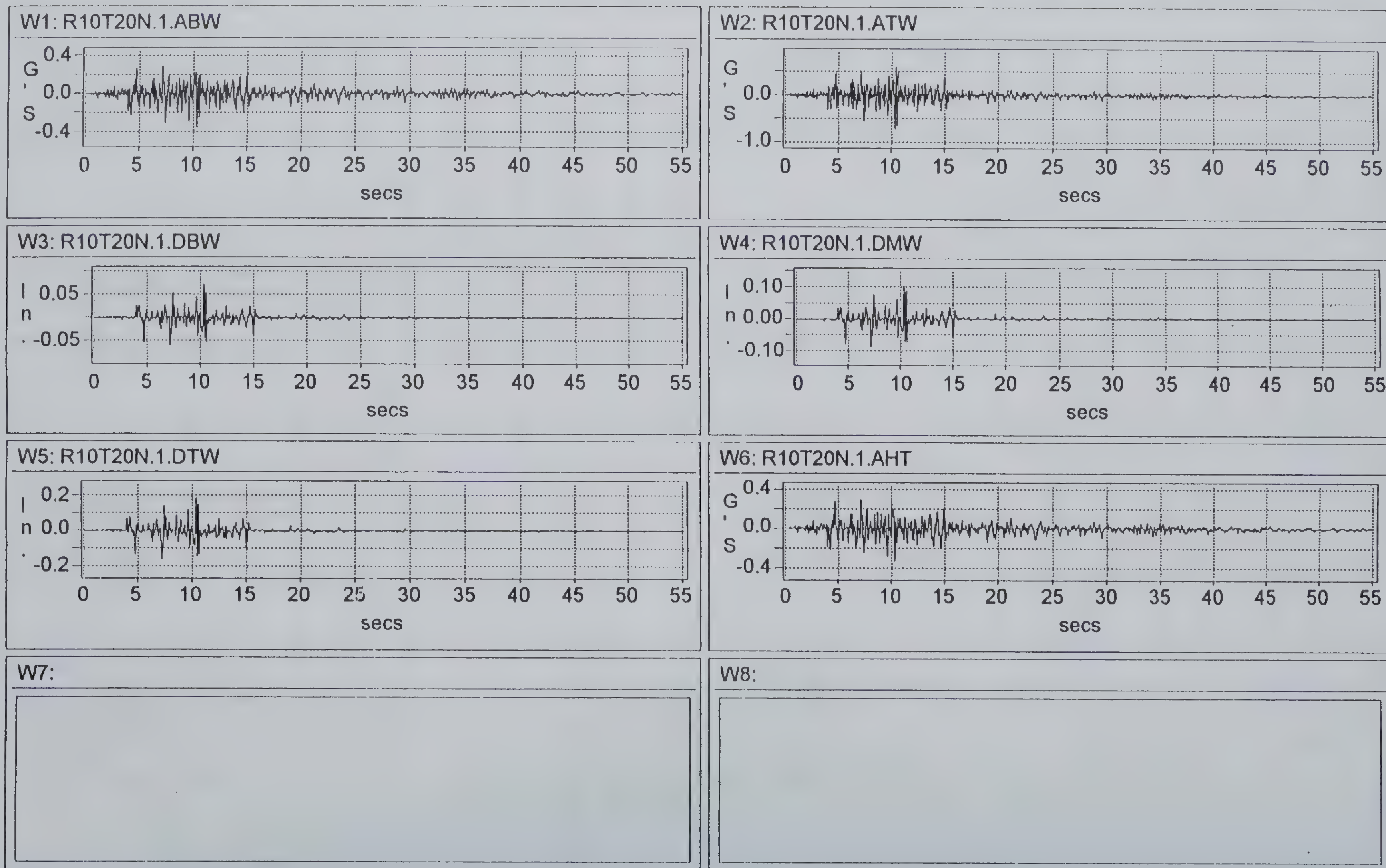

W1: R7EL10F.1.ABW
W2: R7EL10F.1.ATW
W3: R7EL10F.1.AXPIPE
W4: R7EL10F.1.TQPIPE
W5: R7EL10F.1.DBW
W6: R7EL10F.1.DMW
W7: R7EL10F.1.DTW
W8: R7EL10F.1.AHT
secs

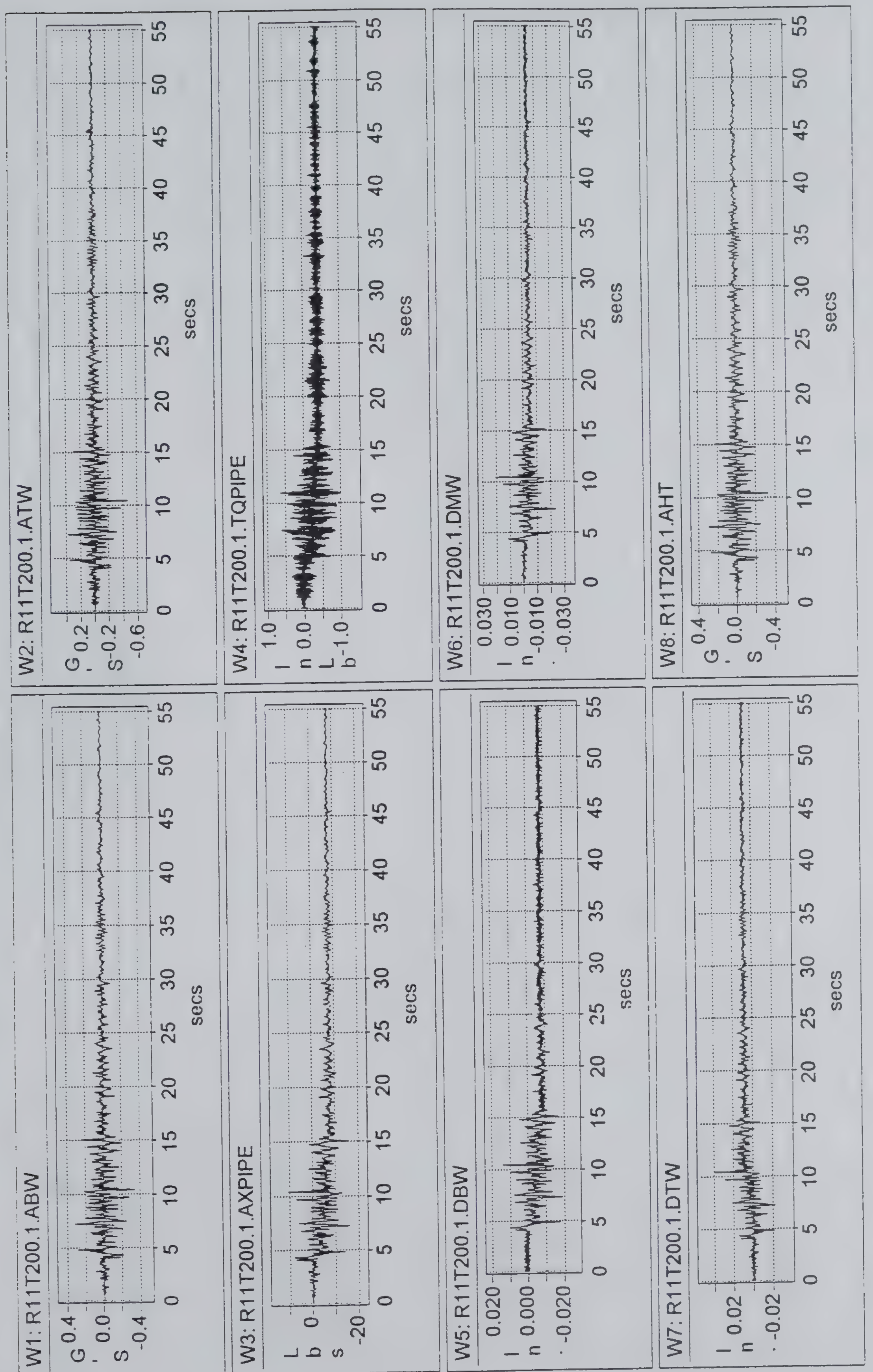

W1: R8TA20F.1.ABW
W2: R8TA20F.1.ATW
W3: R8TA20F.1.AXPIPE
W4: R8TA20F.1.TQPIPE
W5: R8TA20F.1.DBW
W6: R8TA20F.1.DMW
W7: R8TA20F.1.DTW
W8: R8TA20F.1.AHT
G.S
Lbs
In.Lb
In.
secs

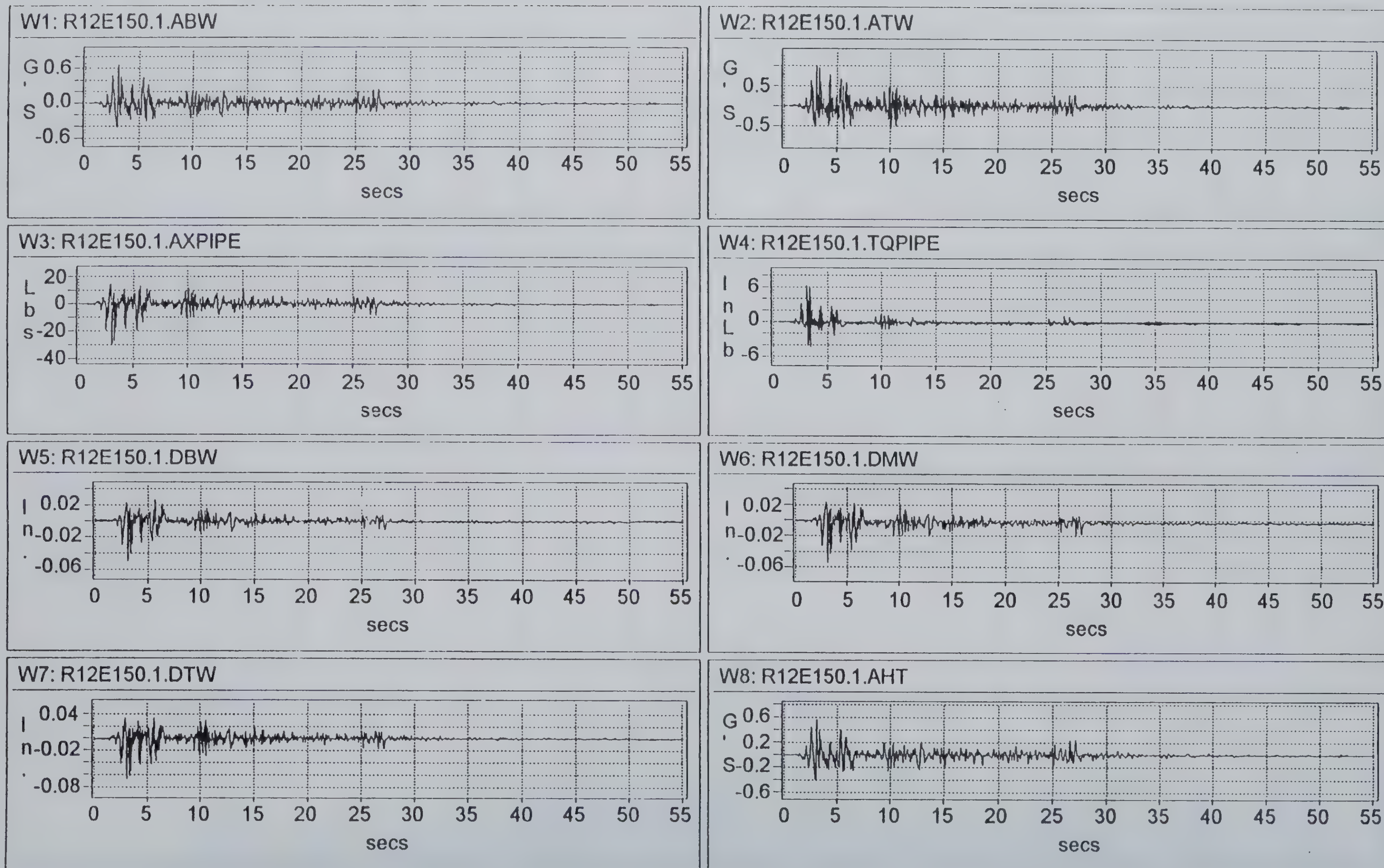

W1: R9EL15F.1.ABW
W2: R9EL15F.1.ATW
W3: R9EL15F.1.AXPIPE
W4: R9EL15F.1.DBW
W5: R9EL15F.1.DMW
W6: R9EL15F.1.DTW
W7: R9EL15F.1.TQPIPE
W8:
secs

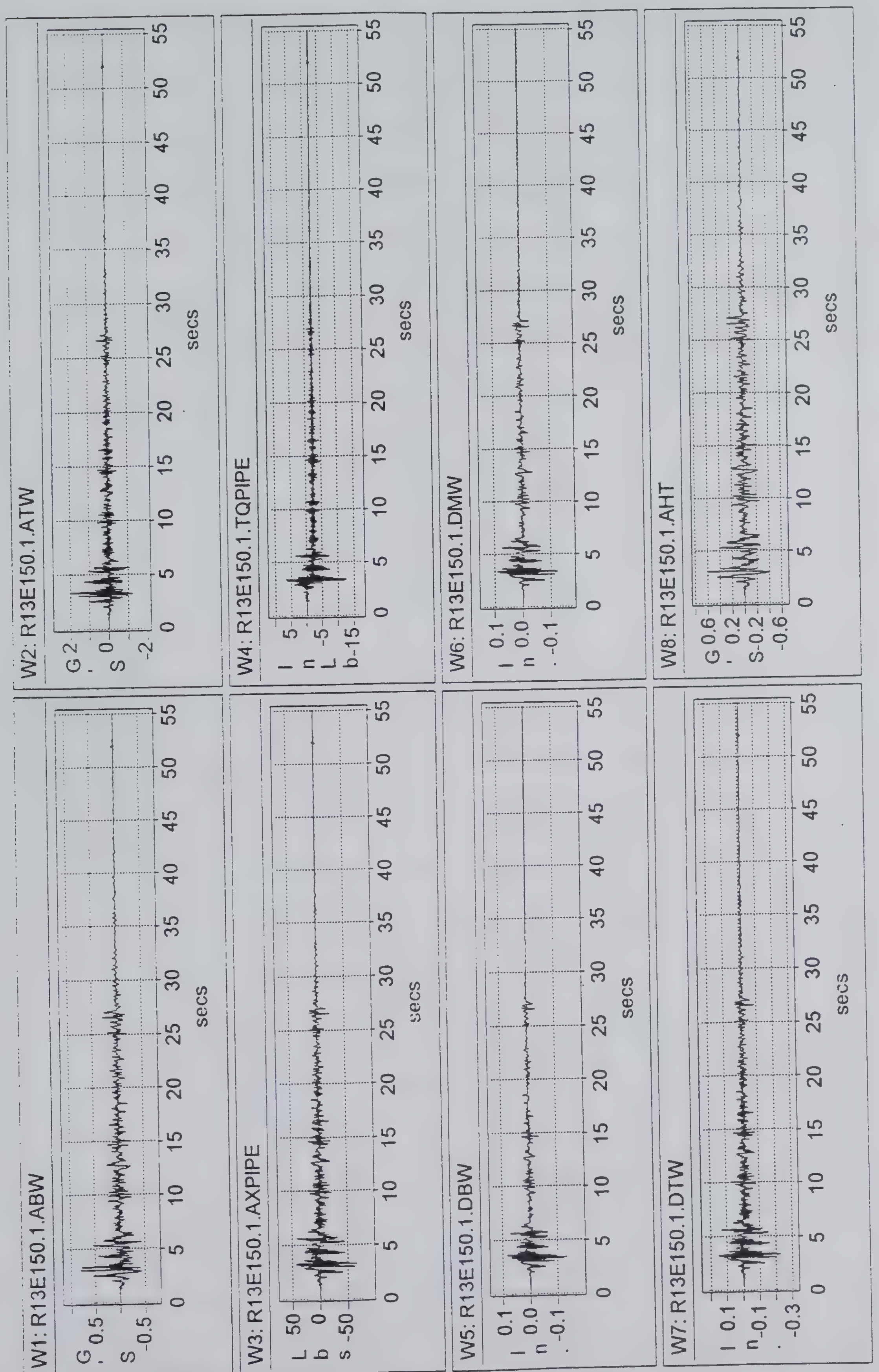


W1: R10E100.1.ABW
G's
secs
W2: R10E100.1.ATW
G's
secs
W3: R10E100.1.AXPIPE
Lbs
secs
W4: R10E100.1.TQPIPE
InLb
secs
W5: R10E100.1.DBW
In.
secs
W6: R10E100.1.DMW
In.
secs
W7: R10E100.1.DTW
In.
secs
W8: R10E100.1.AHT
G's
secs

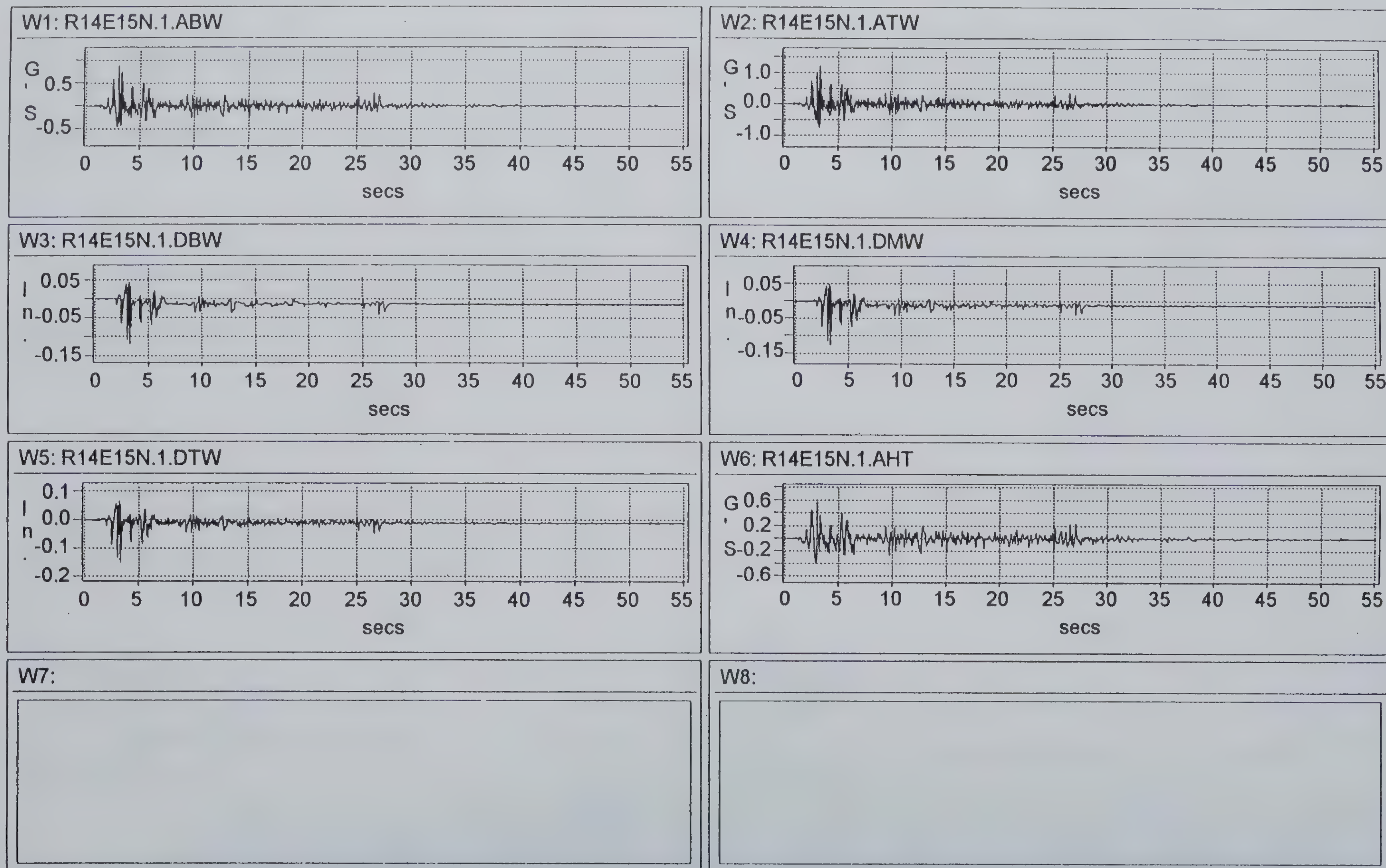

W1: R10T20N.1.ABW
G's
0.4
0.0
-0.4
0 5 10 15 20 25 30 35 40 45 50 55
secs
W2: R10T20N.1.ATW
G's
0.0
-1.0
0 5 10 15 20 25 30 35 40 45 50 55
secs
W3: R10T20N.1.DBW
In.
0.05
-0.05
0 5 10 15 20 25 30 35 40 45 50 55
secs
W4: R10T20N.1.DMW
In.
0.10
0.00
-0.10
0 5 10 15 20 25 30 35 40 45 50 55
secs
W5: R10T20N.1.DTW
In.
0.2
0.0
-0.2
0 5 10 15 20 25 30 35 40 45 50 55
secs
W6: R10T20N.1.AHT
G's
0.4
0.0
-0.4
0 5 10 15 20 25 30 35 40 45 50 55
secs
W7:
W8:


W1: R11T200.1.ABW
W2: R11T200.1.ATW
W3: R11T200.1.AXPIPE
W4: R11T200.1.TQPIPE
W5: R11T200.1.DBW
W6: R11T200.1.DMW
W7: R11T200.1.DTW
W8: R11T200.1.AHT
secs

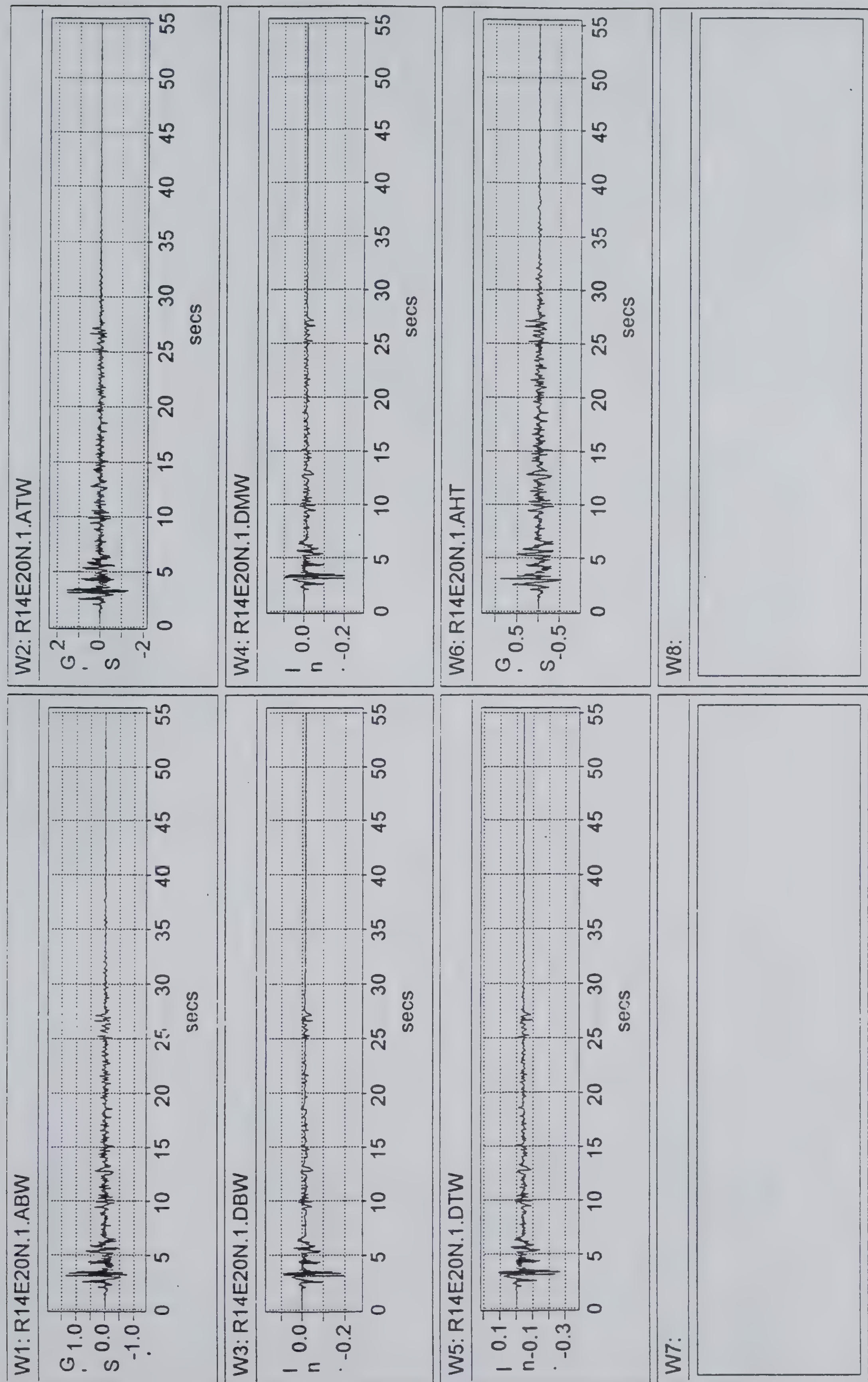

W1: R12E150.1.ABW
W2: R12E150.1.ATW
W3: R12E150.1.AXPIPE
W4: R12E150.1.TQPIPE
W5: R12E150.1.DBW
W6: R12E150.1.DMW
W7: R12E150.1.DTW
W8: R12E150.1.AHT
secs

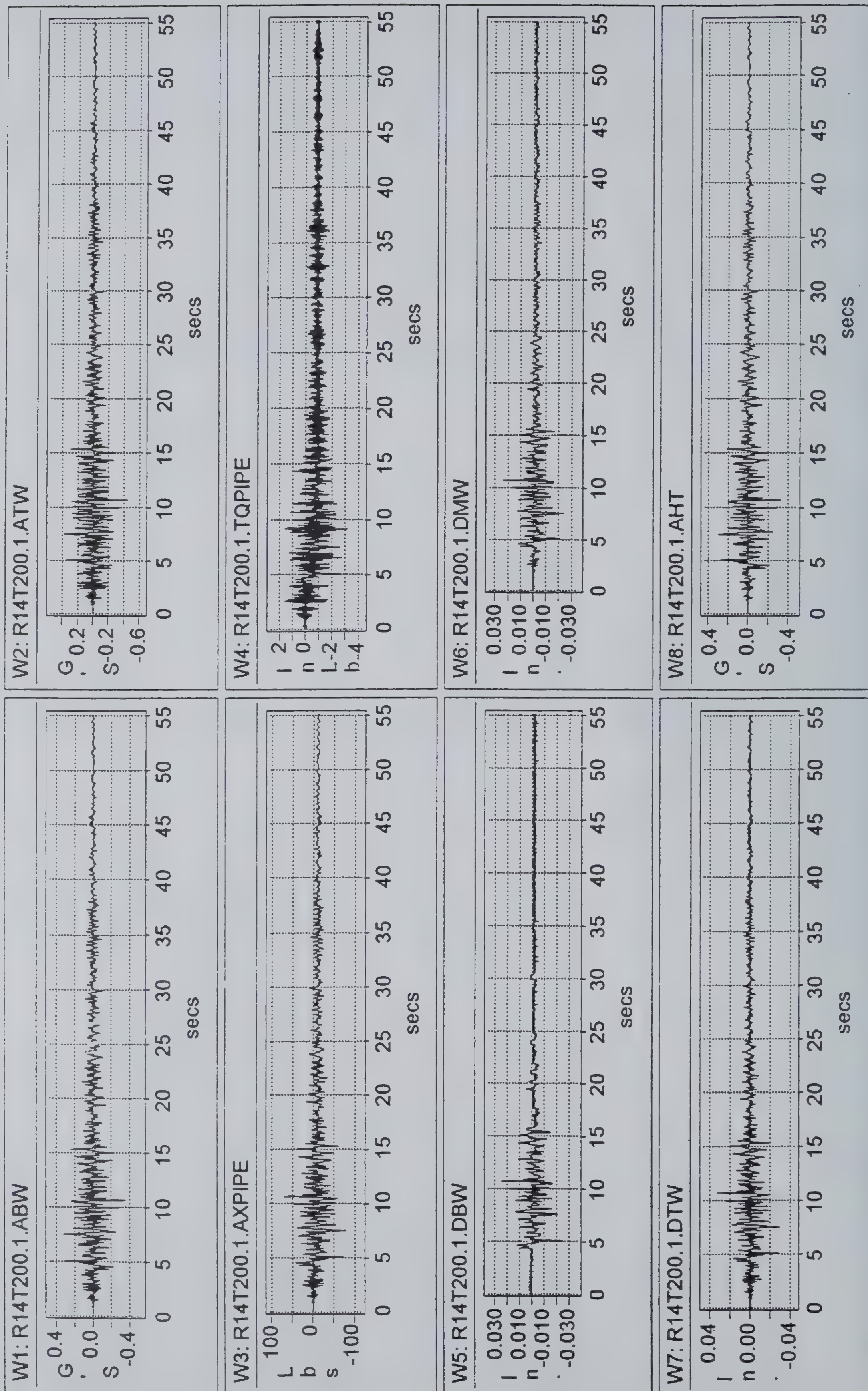


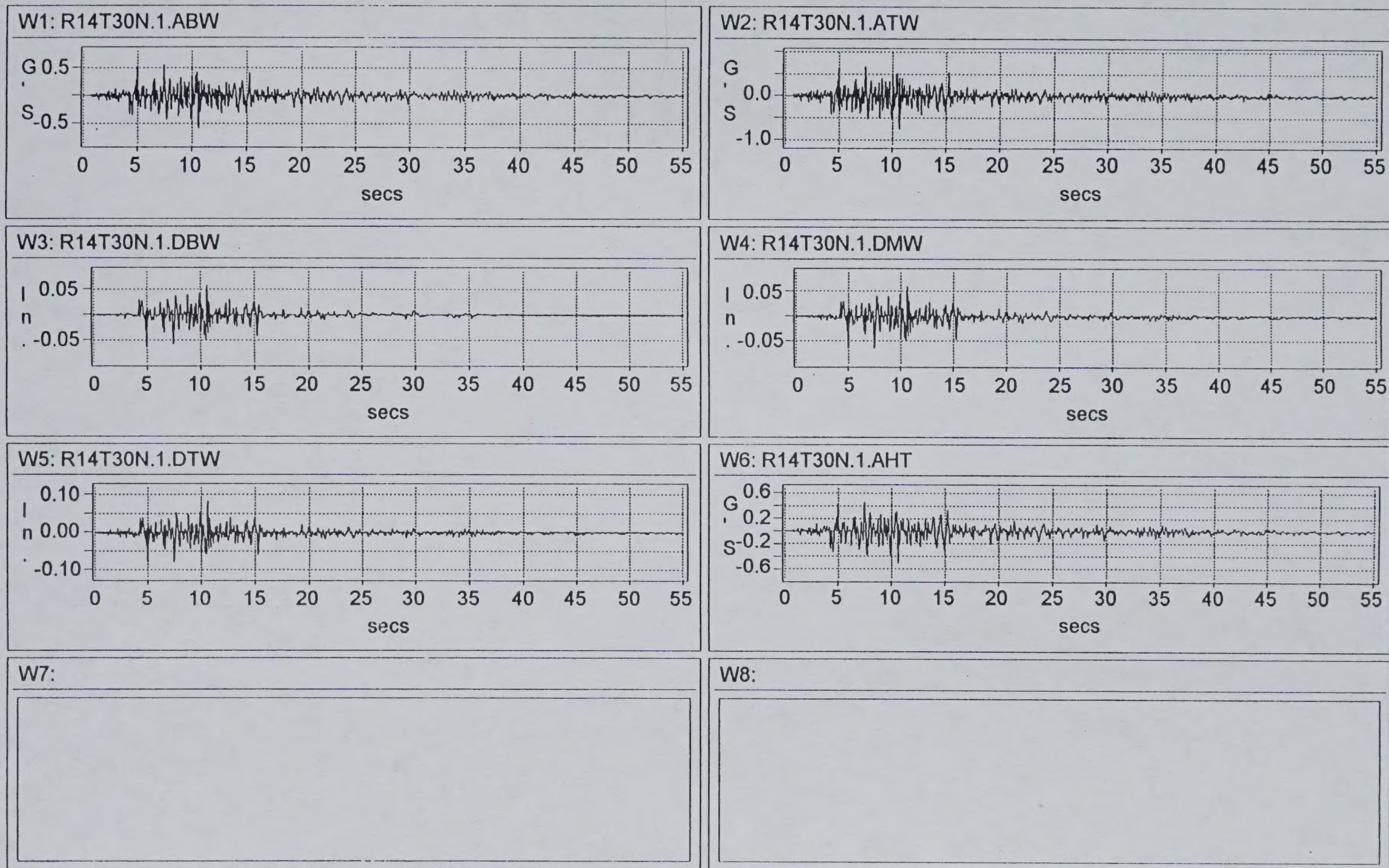
W1: R13E150.1.ABW
W2: R13E150.1.ATW
W3: R13E150.1.AXPIPE
W4: R13E150.1.TQPIPE
W5: R13E150.1.DBW
W6: R13E150.1.DMW
W7: R13E150.1.DTW
W8: R13E150.1.AHT
secs



W1: R14E15N.1.ABW
W2: R14E15N.1.ATW
W3: R14E15N.1.DBW
W4: R14E15N.1.DMW
W5: R14E15N.1.DTW
W6: R14E15N.1.AHT
W7:
W8:
secs


W1: R14E20N.1.ABW
W2: R14E20N.1.ATW
W3: R14E20N.1.DBW
W4: R14E20N.1.DMW
W5: R14E20N.1.DTW
W6: R14E20N.1.AHT
W7:
W8:
secs


W1: R14T200.1.ABW
W2: R14T200.1.ATW
W3: R14T200.1.AXPIPE
W4: R14T200.1.TQPIPE
W5: R14T200.1.DBW
W6: R14T200.1.DMW
W7: R14T200.1.DTW
W8: R14T200.1.AHT
secs


W1: R14T30N.1.ABW
G 0.5
S -0.5
0 5 10 15 20 25 30 35 40 45 50 55
secs
W2: R14T30N.1.ATW
G
0.0
S
-1.0
0 5 10 15 20 25 30 35 40 45 50 55
secs
W3: R14T30N.1.DBW
I 0.05
n
. -0.05
0 5 10 15 20 25 30 35 40 45 50 55
secs
W4: R14T30N.1.DMW
I 0.05
n
. -0.05
0 5 10 15 20 25 30 35 40 45 50 55
secs
W5: R14T30N.1.DTW
0.10
I
n 0.00
. -0.10
0 5 10 15 20 25 30 35 40 45 50 55
secs
W6: R14T30N.1.AHT
G 0.6
0.2
S -0.2
-0.6
0 5 10 15 20 25 30 35 40 45 50 55
secs
W7:
W8: